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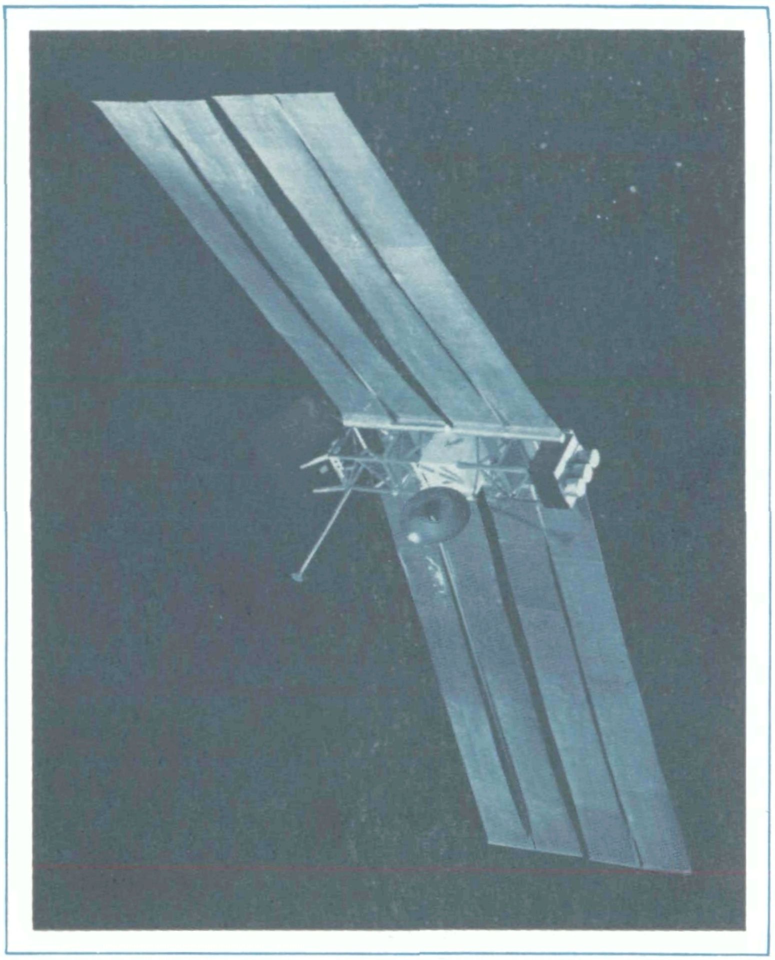

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SOLAR ELECTRIC PROPULSION ASTEROID BELT MISSION STUDY

FINAL REPORT

Volume III
Program Development Plan

Space Division
North American Rockwell

Space Division
North American Rockwell

SOLAR ELECTRIC PROPULSION ASTERIOD BELT MISSION STUDY FINAL REPORT

VOLUME III
PROGRAM DEVELOPMENT PLAN
SD 70-21-3

Contract 952566
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IV

FOREWORD

This Volume III contains the Program Development Plan for the Solar Electric Propulsion Asteroid Belt Mission Program Budgetary and Planning Cost Estimates are included herein as an integral part of the Program Development Plan. The complete study final report documents are as follows:

Volume I	Summary Report, SD 70-21-1
Volume II.	Technical Report, SD 70-21-2
Volume III.	Program Development Plan, SD 70-21-3

ACKNOWLEDGEMENTS

Preliminary Planning	E. J. Laddey
Program Development and Phase B Schedules, and Hardware Utilization List	C B. Brown
Work Breakdown Structure	D. D. Riley
Project Management	T D. Martin, M. R. Johnson
Engineering Development	E. B. Price
Manufacturing	H. E. James
Test	R. A. Gore
Ground Support Equipment	C. D. Jesch
Facilities	C. D. Conrad
Equipment Specifications and Engineering Cost Estimates	E. H. Richardson
Supplier/Subcontractor Cost Estimates	R. P. Dahlquist
Assembly of Engineering Cost Package	E. S. Simone
Pricing	L. R. Hall, C. D. May, Jr.

During this study there were many other individuals within North American Rockwell Corporation Space Division and Hughes Aircraft Company who devoted their efforts and professional knowledge to the program. The persons whose names appear above were the most heavily involved in program development planning.

The Electric Propulsion System Development Plans were prepared by the Hughes Aircraft Company; this effort was headed by Mr. P.S DuPont of the Hughes Space Systems Division.

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INTRODUCTION

PURPOSE AND SCOPE

The purpose of the Program Development Plan (PDP) for the Solar Electric Propulsion Asteroid Belt Mission Program is to describe a logical, integrated, and orderly sequence of activities and events, including the associated management and support, necessary for accomplishment of the established mission objectives. The PDP includes realistic schedules and cost estimates for budgetary and planning purposes, and essential related program information for economical and high-quality one- and two-flight spacecraft programs. In the case of the two-flight program, both vehicles would be ready at the anticipated launch date, the second being available as a backup. The PDP covers definition, design, manufacture, test, ground support equipment, facilities, launch and flight operations support, and related activities for the spacecraft (NASA Phases B, C, and D). The program cost estimate does not include the launch vehicle and deep space network, but is limited to the associated cost of the technical, management, and operational interfaces with the spacecraft.

CONTENT

The PDP is a thoroughly integrated document consisting of seven principal elements:

1. Phase B Plan and Critical Technology Development Recommendations

2. Work Breakdown Structure

3. Program Development Schedule

4. Subsidiary Program Plans

    a. Project Management

    b. Engineering Development

    c. Manufacturing

d. Program Test

e. Ground Support Equipment

f. Facilities

5. Hardware Utilization List

6. Program Cost Estimates

7. Electric Propulsion System Development Plans

APPROACH

North American Rockwell Corporation's Space Division prepared the PDP using the approach shown in Figure 1. This approach is discussed in detail under the various sections of the PDP. Hardware requirements include: a soft mockup during Phase C (to facilitate design engineering and manufacturing planning, and to familiarize JPL and NASA with the spacecraft design); and a number of breadboards, one structural static test article, one development test spacecraft (prototype), one qualification test spacecraft, and one or two flight spacecraft during Phase D. The scheduling analysis, performed in conjunction with the preparation of the Master Program Development Schedule and the schedules of the subsidiary program plans, resulted in a launch date that could be realized by October 1975.

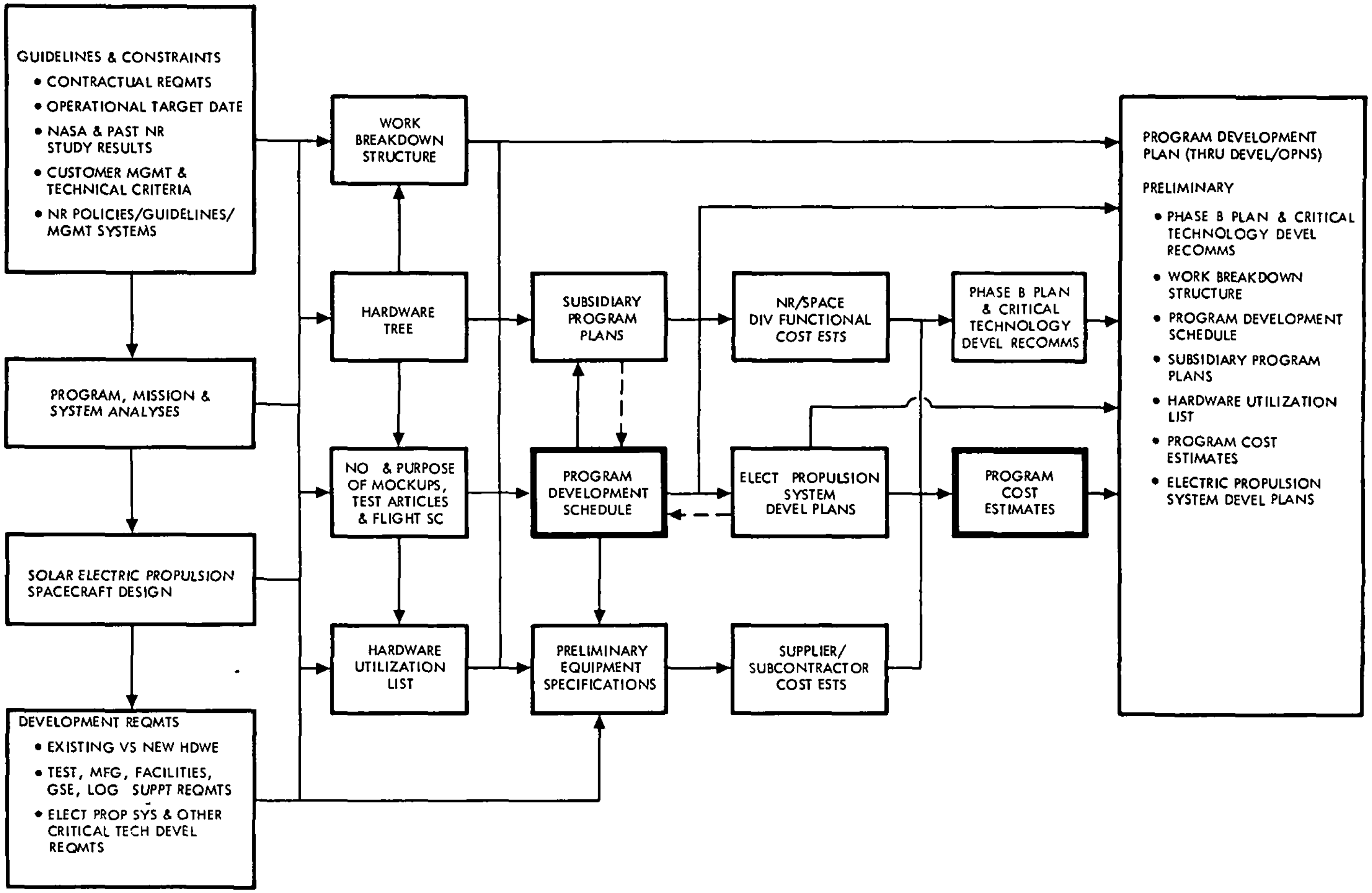

Figure 1. Program Development Plan Approach

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1.0 PHASE B PLAN AND CRITICAL TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

This section of the Program Development Plan contains a preliminary study plan for Phase B (Definition). This section also contains North American Rockwell Corporation's (NR) Space Division comments and recommendations concerning critical items for which technology development should be undertaken (or continued) to ensure orderly and economical accomplishment of the Solar Electric Propulsion Asteroid Belt Mission Program.

1.1 PHASE B (DEFINITION) STUDY PLAN

1.1.1 MAJOR STUDY TASKS

Task 1.0: Study Management

Provide overall planning, direction, and control of the study's technical and management activities, including the Electrical Propulsion System subcontract. Perform liaison with JPL and NASA. Provide interface with contractors engaged in related, critical technology development. Conduct cost and schedule control and manage data and documentation.

Task 2.0: System Engineering and Integration

2.1 Mission and System Analyses — Develop the mission operations concepts and mission and system requirements for the asteroid-belt mission. Establish preliminary mission guidelines, operational constraints, and reliability goals. Develop preliminary mission profile and timeline for asteroid-belt exploration. Determine mission and launch vehicle environments.

2.2 Flight Operations Analysis — Conduct analysis and determine the requirements for the mission operations system and the tracking and data system.

2.3 Launch Vehicle Interface — Establish the launch-vehicle interface requirements for the asteroid-belt mission program including launch vehicle to spacecraft, experiments to spacecraft subsystems, and spacecraft to support equipment.

2.4 System and Subsystems Reliability — Update reliability apportionment as new information becomes available. Provide reliability analysis and trade study support. Participate in preparation of test specifications and procedures. Assess all test plans, including the review and approval of subcontractor and supplier test plans from a reliability viewpoint.

2.5 System and Subsystem Functional Specifications — Prepare system and subsystems functional specifications and the specification tree.

Task 3.0: Spacecraft and Subsystems Preliminary Design

3.1 Spacecraft Integration — Conduct analyses and evaluations for spacecraft weights, loads, dynamics, and acoustics. Identify subsystem functional and physical interfaces for the alternative design concepts (signal; power; interference, both physical and electrical), potential problems. Provide subsystem design coordination and evaluation to aid in the selected integrated spacecraft design configuration Ensure thorough integration of the electric propulsion system into the overall spacecraft design. Support preparation of preliminary development plans, schedules, and cost estimates.

3.2 Structure — Conduct conceptual design studies. Provide preliminary detailed drawings for the selected spacecraft concept. Support preparation of preliminary program plans, schedules, and cost estimates

3.3 Telecommunications and Data Processing — Conduct design trade studies to refine Phase A alternate design concepts; update system functional performance requirements; select desired design concept; and provide definition, including performance, design layouts, schematics, system interfaces, and wire harness. Support preparation of preliminary program plans, schedules, and cost estimates.

3.4 Central Computer and Sequencer — Update and refine central computer and sequencer functional requirements. Conduct design and interface definition trade studies for the purpose of refining the selected configuration concept. Establish computer programming and software requirements. Assess preliminary test requirements and provide technical documentation. Support preparation of preliminary program plans, schedules and cost estimates.

3.5 Guidance and Control — Conduct guidance and control design trade studies to refine the baseline subsystem. Update analytical models and verify subsystem performance via error/sensitivity analyses. Define performance and stability margins (translator control logs). Provide inputs to preliminary design specifications and assess preliminary test requirements. Support preparation of preliminary program plans, schedules, and cost estimates

3.6 Spacecraft Power and Cabling — Conduct design trade studies to refine Phase A alternate design concepts, update subsystem functional and performance requirements, and select desired design concept. Provide configuration definition, including performance, design layouts, schematics, system interfaces, and wire lists. Support preparation of preliminary program plans, schedules, and cost estimates.

3.7 Thermal Control — Conduct design trade studies of alternative concepts and refine the selected design concept. Update analytical models, define the selected thermal control concept, evaluate performance, and provide inputs for preliminary specifications. Assess preliminary test requirements and provide documentation. Support preparation of preliminary program plans, schedules, and cost estimates.

3.8 Roll-up Solar Array and Capacitor-Detector Assembly — Establish design requirements and develop design criteria and specifications for the procurement and utilization of the spacecraft solar panels. Integrate the subcontractor designs, plans, and proposals. Develop recommendations, plans, schedules, and cost estimates.

3.9 Science — Update selected science payloads from the Phase A study. Provide equipment characteristics, functional and performance equipment requirements, interface requirements with respect to the spacecraft, and support requirements. Submit inputs to preliminary design specifications for science payloads and assess their preliminary test requirements. Coordinate and provide support to potential science payload suppliers.

3.10 Pyrotechnic Devices — Identify the pyrotechnic devices functional requirements and specify their physical and operating characteristics. Provide support for preparation of pyrotechnic devices design specifications and assess their preliminary test requirements. Develop the preliminary pyrotechnic devices safety program. Support preparation of preliminary program plans, schedules, and cost estimates.

3.11 Mechanized Devices — Conduct design trade studies to refine Phase A alternate design concepts for mechanized devices. Update the functional and performance requirements for the selected concepts. Provide definition, including preliminary design layouts, schematics, and subsystem interfaces. Support the preparation of the preliminary design specifications. Assess preliminary test requirements for mechanized devices along with suppliers' designs and plans.

3.12 Preliminary Procurement Specifications — Prepare preliminary procurement specifications for all the "buy" items for the Solar Electric Propulsion System Asteroid Belt Mission Program.

Task 4.0: Electric Propulsion System

4.1 Prime Contractor — Establish design requirements and develop design criteria, plans, and specifications for the procurement and utilization of the Electric Propulsion System. Integrate subcontractor's recommendations, designs, plans, schedules, and cost estimates.

4.2 Subcontractor — Conduct electric propulsion system analyses and design studies. Submit recommendations, designs, plans, schedules, and cost estimates to prime contractor.

Task 5.0: Program Development Plan

Prepare an updated Program Development Plan (including work breakdown structure, program development schedule, subsidiary program plans, hardware utilization list, program cost estimates, and electric propulsion system development plans). Prepare updated hardware tree, hardware utilization list, program development schedule, and integrate subsidiary functional schedules.

1.1.2 STUDY SCHEDULE AND MILESTONES

A preliminary study schedule for Phase B delineating the phasing of the major study tasks is shown on Figure 2. The study would be a nine-month effort starting on 1 November 1970 and ending on 31 July 1971. The major milestones, including deliverable items, are shown at the top of Figure 2.

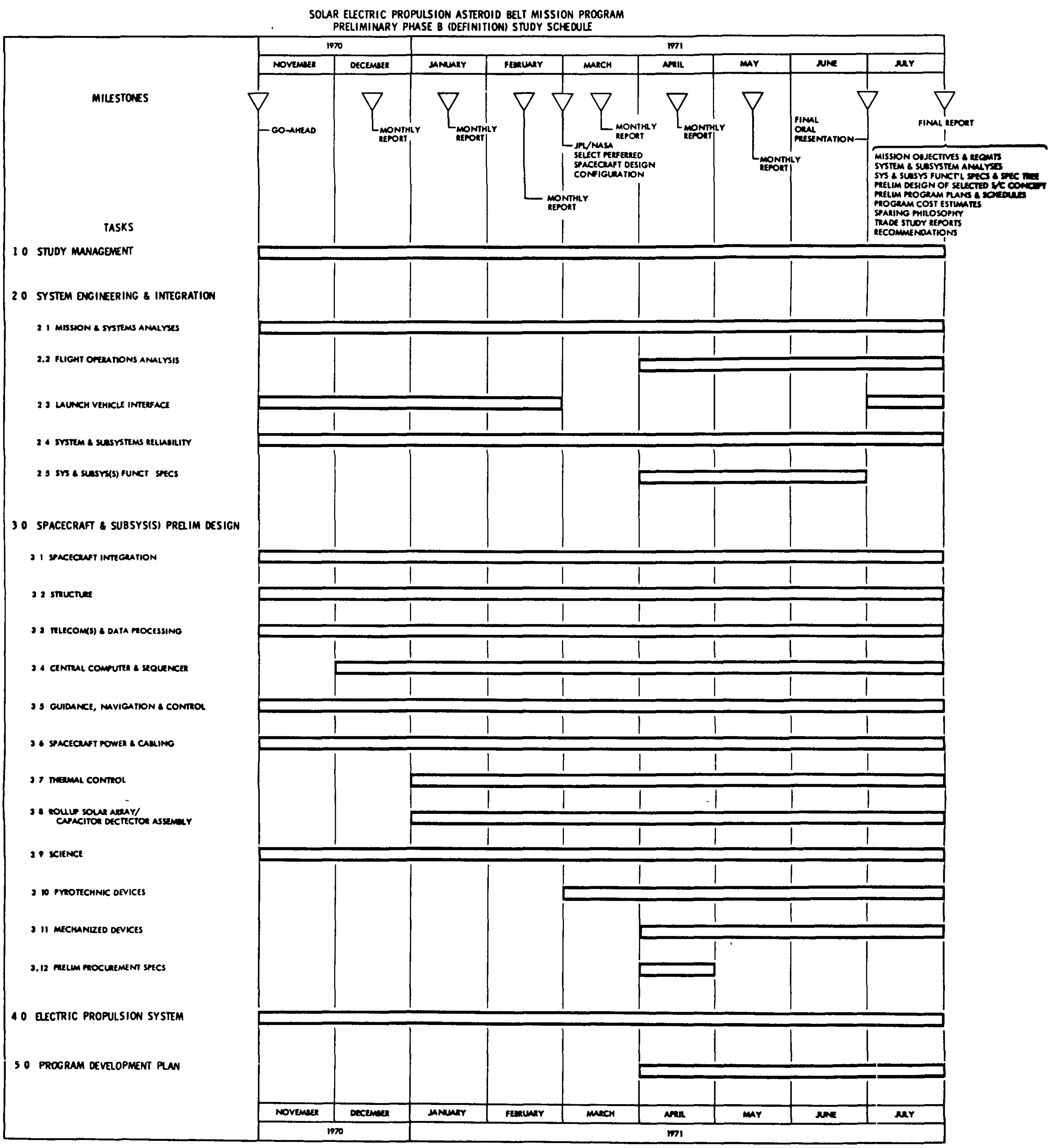

Figure 2. Preliminary Phase B Study Schedule

1.1.3 PHASE B COST ESTIMATE

The estimated cost for a Phase B study is about $490,000 in 1970 dollars, not including profit or fee. This estimate includes $115,000 for a subcontract for an Electric Propulsion System study. Details concerning cost estimates are contained in Section 6.0.

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1.2 CRITICAL TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

1.2.1 INTEGRATED ROLL-UP SOLAR ARRAY AND METEOROID DETECTOR

The basic concept of integrating a capacitor sheet meteoroid detector with the roll-up solar array involves new technology considerations. Potential technical problems that may occur include bonding of the capacitor sheets to the solar cell substrate, curl effects due to roll-up of the metallic capacitor sheets when in the stored position, and electrical interference and/or influence on the performance of the solar array and the capacitor sheet meteoroid detector.

A technology development program is recommended to resolve the feasibility and identify critical design problems associated with the concept of the integrated solar array/meteoroid penetration detector. This program should include: (1) roll-up testing to provide information on the quality of bonding of the detector to the solar array substrate and on the allowable thickness of detector sheet to avoid excessive curl effects when deployed, (2) electrical interaction between the solar cells and the detector to determine any degrading effects on solar array performance and to determine influence on possible false alarm impact indication of detector; and (3) penetration tests to verify theory of particle size determination when the capacitor sheet detector is mounted on the back of the solar array substrate.

1.2.2 INTEGRATED ELECTRIC PROPULSION SYSTEM DEVELOPMENT

An integrated electric propulsion system development program is strongly recommended to be conducted before entering into Phase D (development/operations) of the Solar Electric Propulsion Asteroid Belt Mission Program. Such a technology development program should plan for a complete systems demonstration of all facets associated with the incorporation of solar electric ion propulsion aboard an unmanned interplanetary spacecraft. The integrated system should demonstrate such facets as: (1) Thrusters switching logic and control electronics, (2) power matching and peak power tracking and controls, (3) utilizing a thruster array mechanically interfaced with a two-degree-of-freedom translator for thrust vector position control and spacecraft attitude control about two axes, and (4) gimbal (hinged) thruster modules for spacecraft control about the vehicle roll axis. A program that would include all the above system aspects would

ensure that electric propulsion, as a prime propulsion system, could be made available within the program schedule for the asteroid belt mission. The recommended electric propulsion technology development and test program is described in Volume II of this final report in the electric propulsion system, Section 6.0. The cost of such a technological program has not been included as part of the overall asteroid belt mission spacecraft program described in this Program Development Plan.

1.2.3 SCIENCE

The mission concept envisions the use of new science equipments — Sisyphus and the electrostatic ballistic pendulum (EBP). Prior to the scheduled flight for the asteroid belt mission, a small version (8 inch-diameter reflector) of the Sisyphus equipment will have been flown on the Pioneer vehicle. Results of this flight may preclude the necessity of a major development effort to provide a similar system with large reflector diameters (67 cm). However, the nature of the asteroid belt mission is such that cometary impact on the surface of the reflector may result in surface pitting, thereby degrading the ability to predict particle size since reflector efficiency will be unknown. Some testing of Sisyphus reflector performance with various degrees of surface pitting is required to determine uncertainty of particle size measurements.

The electrostatic ballistic pendulum has been under research development for several years at various levels of effort by industry and NASA. An equipment development effort should be continued to ensure that long mission lifetime operation will be achieved. Also, impact testing should be conducted to generate data for statistical validity for calibration of the EBP.

2.0 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) lists the principal categories of hardware, software, services, and other tasks that comprise the Solar Electric Propulsion (SEP) Asteroid Belt Mission Program. The WBS (Figure 3) is product-oriented to the major component level. It provided a frame of reference for the preparation of the Program Development Schedule, subsidiary program plans, and program cost estimates.

The spacecraft hardware portion of the WBS reflects a hardware tree derived from an analysis of the SEP spacecraft design. To facilitate identification of development and production costs, the WBS contains separate breakdowns for test and flight hardware. Although the soft mockup is not a test article, it is listed in the test hardware grouping for convenience in accumulating cost estimates and to simplify the WBS.

The WBS does not include the launch vehicle or deep space network operation. However, the WBS does provide for their technical, management, and operational interfaces with the spacecraft under Launch Operations Support (Item 9.0) and Flight Operations Support (Item 10.0).

The other entries on the WBS (Spacecraft Project Management, System Engineering and Integration, Facilities, etc.) are based on Space Division experience, tailored to this program.

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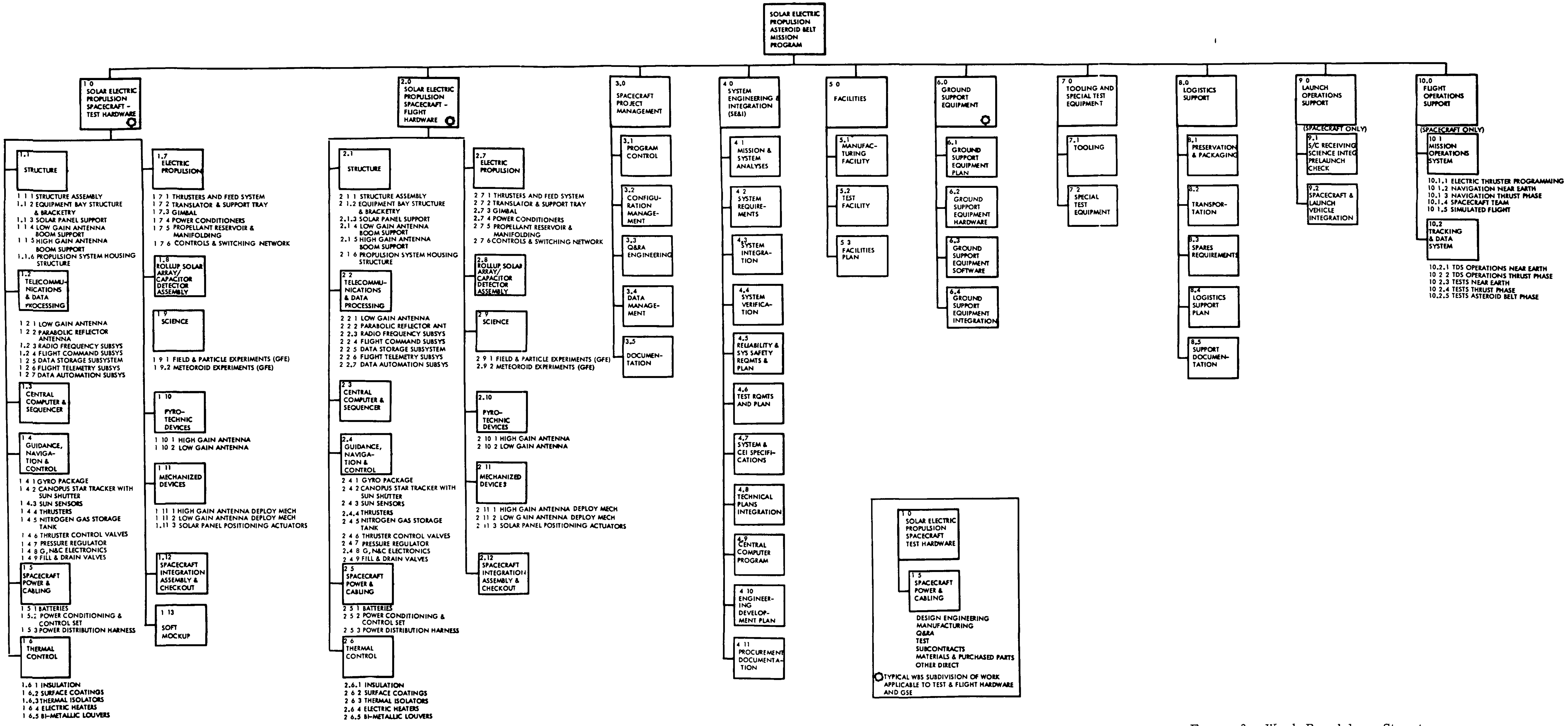

Figure 3. Work Breakdown Structure

3.0 PROGRAM DEVELOPMENT SCHEDULE

The preliminary Program Development Schedule (Figure 4) shows a total integrated set of activities and milestones for the design, development, production, and utilization of spacecraft for the SEP Asteroid Belt Mission Program. The schedule is based on the spacecraft design described in the technical sections of this report (Volumes I and II) and shows an orderly evolution of events leading to an operational system.

3.1 APPROACH

The approach for the preparation of the Program Development Schedule included the following steps:

1. Establishment of ground rules and assumptions.
2. Consideration of schedule data on Mariner projects obtained from the Jet Propulsion Laboratory.
3. Application of schedule data from NR hardware programs.
4. Extraction of pertinent information from NR studies on unmanned spacecraft.
5. Extraction of applicable data from technical analyses conducted during the current study.
6. Preparation of a preliminary hardware tree, reflecting the SEP spacecraft design. The hardware tree assured that all spacecraft subsystems and components were considered for development analysis.
7. Preparation of a Work Breakdown Structure. The WBS identifies the hardware, software, services, and other tasks that had to be taken into account in preparing the Program Development Schedule, program plans, and cost estimates.
8. Determination of the number and purpose of mockups, test articles and test spacecraft, and flight spacecraft.

9. Preparation of a Hardware Utilization List (HUL), which gives total program requirements for major components of spacecraft hardware and ground support equipment; the HUL was derived from the hardware tree and included make-or-buy considerations.

10. Analyses of the previous information and translation of the system and subsystem requirements into development requirements.

11. Preparation of subsidiary program plans (those significantly affecting the cost estimates), including related schedules, for Project Management, Engineering Development, Manufacturing, Program Test, Ground Support Equipment, and Facilities.

12. Construction of the Program Development Schedule through an iterating process which took into account all the above factors.

3.2 GROUND RULES AND ASSUMPTIONS

NR established specific ground rules and planning assumptions in order to maintain a program baseline and frame of reference in the preparation of the Program Development Schedule. These ground rules and assumptions are:

1. In accordance with the JPL contract Statement of Work, a single schedule is required covering both one- and two-flight spacecraft programs.

2. This study (JPL Contract No. 952566) has accomplished the Phase A (Preliminary Analysis) requirements.

3. A Phase B (Definition) study contract will start during the latter part of calendar year 1970. A nine-month period is allowed for evaluation before commencing Phase C. With NASA and JPL concurrence this period may be shortened.

4. A single contract will be awarded for Phases C (Design) and D (Development and Operations).

5. Launch is assumed to take place during 1975 from the Kennedy Space Center.

6. One or two flight-ready spacecraft will be available at the launch date.

7. Existing North American Rockwell facilities (or equivalent) and nearby Government installations will be utilized; requirements for modified or additional facilities and related equipment will be kept to a minimum.

8. The Program Development Schedule should define an orderly, economical evolution of events leading to the realization of mission objectives (i.e., first, demonstration of SEP as a prime propulsion system for unmanned interplanetary exploration, and, second, performance of a survey of the environment in the asteroid belt region). The phasing of the program should not be considered as fixed, except for meeting a 1975 launch date.

9. The Program Development Schedule should be prepared on the basis of close coordination with all functional activities. Action should be taken to assure that the Program Development Schedule, the Electric Propulsion System Hardware Schedule, and the schedules in the individual subsidiary program plans are consistent.

3.3 DISCUSSION

The preliminary Program Development Schedule, showing the major milestones and program activities, was developed in coordination with Engineering, Manufacturing, Test, Ground Support Equipment, Facilities, and other functional organizations. This schedule designates the desired delivery of test spacecraft and flight spacecraft, but does not give precise Manufacturing, Test, and other functional milestones. Detailed schedules for each of the major functions are found in the subsidiary program plans, which are covered in another part of this volume.

The phasing of the program is as follows:

1. A 10-month period has been designated for JPL review of the current Phase A study, JPL in-house studies and budget planning, plus contractor in-house studies and supporting research and technology.

2. A nine-month Phase B study is scheduled from 1 November 1970, through 31 July 1971.

3. The Phase B study will be followed by nine months for review, in-house studies, and budgeting, plus contractor in-house studies and supporting research and technology.

4. Phase C will start on 1 May 1972 and last for nine months, to 31 January 1973.

5. Phase D will commence immediately thereafter (1 February 1973) and continue for 32 months, launch being scheduled for 1 October 1975.

6. The total time for Phases C and D is 41 months.

The schedule shows that during the Phase C design study, a spacecraft soft mockup will be fabricated, with completion to coincide with the Preliminary Design Review (PDR) date. PDR is scheduled for 1 December 1972, two months before the completion of Phase C. Major outputs during Phase C will include: (1) preliminary design of subsystems, (2) CEI, Part I Performance Specifications, (3) updated program plans and schedules, and (4) detailed cost estimates for Phase D.

For Phase D (Development and Operations) the Program Development Schedule shows the scheduling requirements for both the one-flight spacecraft program and the two-flight spacecraft program. In the case of the former it is assumed that the qualification test spacecraft could be made available as a backup, if required and initially planned for in the program. For the two-flight spacecraft program it is assumed that the second flight spacecraft would serve as a backup; the qualification test spacecraft would be used for other program purposes (i. e., the operational spacecraft simulator or for assembled spares).

The Program Development Schedule depicts the major milestones for each of the principal program functions during Phase D. Program plans will be updated and implemented as soon as possible after Phase D go-ahead. Project management will implement the schedule and cost and technical performance functions. Detailed development and production design effort will begin at the start of Phase D, with the Critical Design Review (CDR) scheduled three months later. Eighty percent of the detail drawings are scheduled for release at CDR, with the remaining 20 percent scheduled for release within the next two months to assure meeting Manufacturing scheduling requirements.

A comparison of the one- and two-flight spacecraft programs indicates that the same number of test articles and spacecraft will be required: one structural test article, one development test spacecraft (prototype), and one qualification test spacecraft. The Manufacturing and Testing net time spans are the same for both programs, but the calendar time sequencing is different, as reflected on the Program Development Schedule. The main reason for the differences in Manufacturing and Test sequences between the one- and two-flight spacecraft programs is that the schedule reflects the minimum program requirements for ground support handling equipment and checkout equipment. Under the two-flight spacecraft program, Flight Spacecraft No. 1 will have a 2-1/2-month storage period after completion of the acceptance test in order to eliminate the need for two sets of handling and checkout equipment. A breakdown of the detail manufacturing processes and the detail manufacturing schedules are found in the Manufacturing Plan. Detail test procedures and schedules are found in the Program Test Plan.

The Program Development Schedule shows activity bars with some of the key milestones for the following support functions: Procurement, Facilities, Ground Support Equipment, Logistics Support, and Flight Operations Support.

Major program technology factors are completion of electric propulsion system integration development, roll-up solar array/capacitor-type meteoroid detector assembly development, and—to a lesser extent—experiment development. The Program Development Schedule shows individual activity bars for each of these technology areas. Development of the complete electric propulsion system integration and the roll-up solar array/capacitor-type meteoroid detector assembly are scheduled to commence on, or shortly after, the start of Phase B, or approximately three years prior to their requirement dates for the spacecraft test program.

It is the opinion of North American Rockwell Space Division management that this Program Development Schedule is feasible. The time spans for each of the concurrent system development requirements are realistic. There is minimum slack for unforeseeable program delays or test failures. Phasing for various activities and milestones was based on consultation with design project engineers, with test operations, manufacturing, and facilities engineers, and with other functional support personnel.

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SOLAR ELECTRIC PROPULSION ASTEROID BELT MISSION PROGRAM
PRELIMINARY PROGRAM DEVELOPMENT SCHEDULE

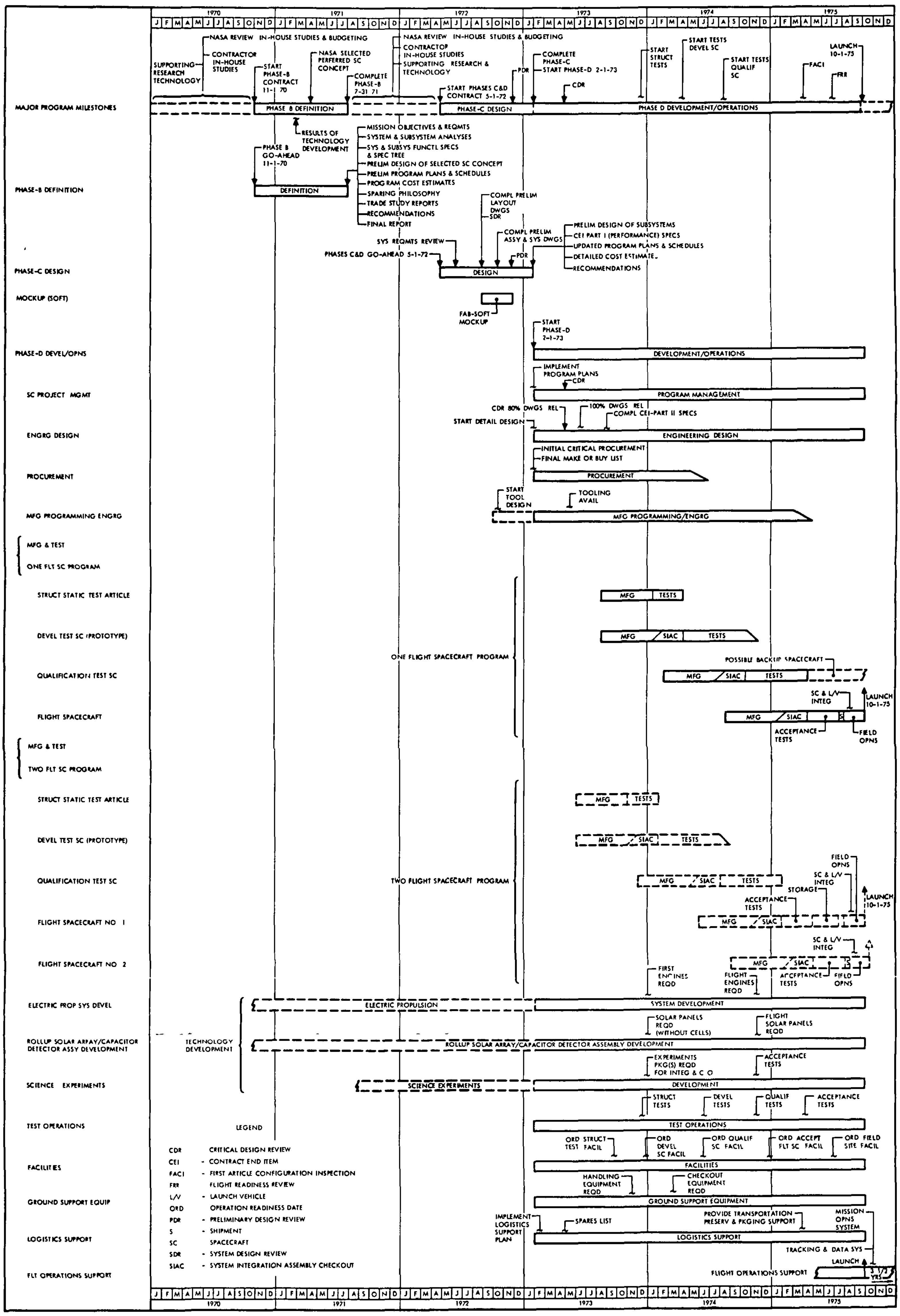

Figure 4. Preliminary Program Development Schedule

4.0 SUBSIDIARY PROGRAM PLANS

The purpose of the subsidiary program plans for the Solar Electric Propulsion (SEP) Asteroid Belt Mission Program is to set a course of action for achieving mission objectives and to communicate that course, in order to accomplish the objectives: (1) at the lowest practical overall development and production costs; (2) on time with respect to the target launch data; and (3) in accordance with JPL's and the NASA's quality standards. The plans also provide a basis for identification of deliverable products, and realistic program cost estimates and development schedules; and ensure functional integration of the various parts and activities of the program.

The scope of the planning activity required for this program is extremely broad, encompassing all program technical and management functions, including system engineering and design, manufacturing, test, facilities, ground support equipment, logistics support, cost and schedule control, configuration management, etc. NR Space Division has selected a limited number of key functional areas for which preliminary plans are considered useful at this time and commensurate with the depth of this five-month study contract. These functional areas and corresponding plans consist of: Project Management, Engineering Development, Manufacturing, Program Test, Ground Support Equipment and Facilities. During subsequent phases of this program these plans will be updated and expanded, and additional program plans required will be prepared.

The preparation of these preliminary plans constituted a fundamental part of the total mainstream management and technical processes of this Phase A contract. NR thoroughly integrated the preparation of the plans with the conduct of the other contractual activities. The plans basically reflect the requirements of the current contract and overall program. Requirements evolved and expanded from technical analyses conducted during the study. There was a comprehensive assessment and iteration of the technical and programmatic interfaces among the spacecraft, ground support equipment, and facilities.

The plans provide across-the-board functional integration of the various parts and activities of the program. The SEP spacecraft design that evolved during the study provided a frame of reference for the preparation of the plans. The Work Breakdown Structure, with which the plans are consistent, exerted a strong integrating influence. The plans reflect the requirements for the soft mockup, test articles, and flight spacecraft; and

the preliminary Hardware Utilization List. The schedules and milestones for individual plans evolved in consonance with the evolution of the overall Program Development Schedule. NR integrated the preparation of each plan with the other plans. The plans are in conformance with applicable NASA management and technical criteria and NR management system and guidelines. The plans also reflect NR's broad, past experience. The balance of this section covers the individual plans.

4.1 PROJECT MANAGEMENT PLAN

4.1.1 PURPOSE

The purpose of the Project Management Plan is to ensure economical and effective overall planning, organization, staffing, direction, and control of the spacecraft project activities of the Solar Electric Propulsion (SEP) Asteroid Belt Mission Program.

4.1.2 SCOPE

The Project Management Plan covers the Project Manager's role, project-wide cost and schedule control, configuration management, subcontract management, data management and make-or-buy determinations. This Plan is specifically applicable to Phases C (Design) and D (Development/Operations). The same principles apply to Phase B (Definition).

4.1.3 TASK DESCRIPTIONS

4.1.3.1 Requirements

Strong, comprehensive project leadership and controls are essential to avoid cost overruns, serious delays in flight readiness dates, inadequate control of system and subsystems design evolution, loose subcontract award and administration, excessive and/or improperly scheduled data and documentation, and uneconomical make-or-buy decisions.

4.1.3.2 Management Approach

The size and complexity of this project must be kept in focus in planning, organizing, staffing, directing, and controlling the SEP program. There should be a minimum number of management personnel. Staffing for control functions should be adequate but austere. Responsibility assignments for work effort should be on the basis of work packages derived from the Work Breakdown Structure. The services of qualified supportive personnel should be obtained from cognizant central functional organizations throughout the company—for specific tasks and for specific time periods. The personnel should be returned promptly to their central functional organizations when their assignment is completed.

The contractor shall be completely responsive to JPL and NASA management and technical criteria. Maximum use should be made of existing Company management systems and procedures, tailored to this project, paperwork being kept to a minimum. There should be minimum requirements for new facilities and support equipment.

The Spacecraft Project Manager should have complete authority and responsibility for all personnel working on the Project for the life of the Project. In the interests of efficiency, all personnel (other than off-site) working on the project should be centralized in one location.

4.1.3.3 Task Summary

Spacecraft Project Manager

The Spacecraft Project Manager should be directly accountable to Division executive management and carry the delegated authority of the President when directing project personnel in achieving project objectives. The Project Manager shall be specifically responsible for:

- Directing the Solar Electric Propulsion Asteroid Belt Mission Program toward successful completion as dictated by the contract
- Participating in contract negotiations
- Establishing overall project performance baselines to meet contractual requirements on project cost, schedule, and technical performance
- Approving all project plans, specifications, and schedules
- Approving project implementing instructions and assuring that such instructions are within the boundaries of Division policy
- Authorizing and controlling all project funds with sole accountability to Division executive management
- Assessing actual performance against plans and providing remedial action when required
- Acting as the prime JPL/NASA interface for all matters that directly affect the project
- Organizing the project for effective management

- Selecting and approving management personnel assigned to the project
- Approving the Project Master (Program Development) Plan and ensuring that revisions to it are properly authorized, issued, and implemented
- Directing and approving the issuance of work authorizations to assigned work package managers
- Maintaining constant awareness of overall project status and taking appropriate action on critical problems
- Assuring that work package authorizations conform to project objectives
- Assuring that the management system identifies problems and potential problems, and approving corrective action
- Providing a forecast to the work package managers and central functional organizations regarding future project requirements for manpower, facilities, etc
- Serving as Chairman of the Configuration Control Board, and approving all decisions recommended by the Board
- Serving as Chairman of the Project Make-or-Buy Committee, and approving decisions made by the Committee
- Defining the requirements for a project management system necessary to satisfy contractual obligations
- Reviewing all aspects of the project with the Division executive management on a scheduled basis
- Approving correspondence and other communications with the JPL/NASA that concern the project.

Cost and Schedule Control

Cost Control. Total budgetary responsibility shall be assigned to the Project Manager. He shall direct the project effort by issuing work package authorizations to responsible work package managers or subcontractors. These work package authorizations shall identify specific effort, time-phased budgets including all direct costs, specific schedule activity, and required

interfaces with other work package managers in accordance with the SEP Work Breakdown Structure. After entering these cost and schedule baselines into the computer module, the cost data will be available for comparison with actual expenditures, and integration with schedule data from the automated schedule module. Project cost visibility can be obtained through variance analysis of budgeted costs for work scheduled against actual costs of work performed. Project summary and functional/product oriented reports shall be prepared and made available to the Project Manager, the work package managers and functional managers on both a weekly and monthly basis. These reports will provide the basis for management analyses of project cost status and accomplishment of cost objectives. The basic computer data will also provide a cost tradeoff capability to assist in making cost effective decisions. Required cost status reports shall be submitted to JPL and NASA

Schedule Control. The Master SEP Program Schedule shall be the baseline for the iterative process of developing and later monitoring detailed subordinate schedules for each work package. Detailed schedules also shall be developed and monitored for subcontract items. Schedule control also shall include: reviewing schedule status and program milestones; revising the Master Schedule; coordinating schedule data; updating schedule logic networks; performing schedule analysis; preparing biweekly computer inputs; providing work package schedule status/analysis biweekly to the Project Manager and work package managers, and preparing schedule status reports for submittal to JPL and NASA.

Subcontract Management

The basic tool for control of subcontractors' effort shall be work package authorizations which require the subcontractors to prepare cost, schedule and performance reports. Each subcontractor work package shall identify time spans and release schedules, performance specifications, Configuration Management requirements, and specific reporting requirements. Reporting information shall be incorporated into the project integrated management system for planning and control visibility.

Configuration Management

Immediately after Phase C/D contract go-ahead, the contractor shall establish a Configuration Control Board and shall designate the board chairman (Spacecraft Project Manager), secretary and functional department representatives. Concurrent with this action, the Configuration Management (CM) organization will be initiated and shall invoke CM on all Solar Electric Propulsion Asteroid Belt Mission functional organizations such as Engineering, Manufacturing, Test, Material, Quality and Reliability Assurance, Logistics,

and the subcontractors. Prior to Preliminary Design Review a formal Configuration Management Requirements Plan shall be issued for total project integration that includes all SEP elements. This plan shall be updated periodically and shall become a baseline CM document at the Critical Design Review. To accomplish CM requirements, systems and procedures shall be placed in effect sequentially to ensure that all aspects of Configuration Management identification, control, accounting, and assurance interface properly in their respective roles. Monitoring of all CM elements shall continue during the entire life cycle of the Solar Electric Propulsion Asteroid Belt Mission Program.

Data Management

Data Management for this project shall consist of the planning, programming, organizing and implementing of a total data and documentation requirement throughout the contractual period. This includes the identification, definition, scheduling, control, indexing, cataloging, recording, implementing, and maintaining of essential contract data requirements for the prime contractor and subcontractors to adequately satisfy contract and project management requirements. Data shall be submitted to JPL or NASA in compliance with the Contract Data Requirements List and Data Requirements Descriptions.

Make-or-Buy Determinations

The prime contractor shall be responsible for integrating, assembling and checking out the spacecraft. As may be noted from an examination of the Hardware Utilization List (Table 6, page), it is anticipated that the prime contractor would also manufacture the structural components, Guidance, Navigation and Control thrusters; power distribution harness; electric propulsion system translator and support tray; the mechanized devices; some of the Ground Support Equipment; and the soft mockup.

It is anticipated that most of the Science payload and a few articles of Ground Support Equipment would be Government-furnished.

Major components anticipated to be "buy" items and potential suppliers and subcontractors include the following:

Major Component	Potential Suppliers and Subcontractors
• Low gain antenna and parabolic reflector	JPL
• Travel wave tube amplifier	Hughes

Major Component	Potential Suppliers and Subcontractors
• Filter/hybrid coupler, diplexer, transponder receiver, radio control unit and switches	Philco, Motorola
• Flight Command Subsystem	Motorola, Litton Industries
• Data storage subsystem recorders	Philco, Motorola
• Flight Telemetry System	Taft Electronics
• Data Automation System	Taft Electronics
• Central Computer and Sequencer	Motorola
• Gyro Package	Timex
• Canopus Star Tracker - with sun shutter	Honeywell
• Fine and coarse sun sensors	Bendix
• Nitrogen Storage Tank	Air Tec Division of Fansteel
• Thruster control valve, pressure regulator, and fill and drain valves	Carleton Controls
• Power conditioning and control set, with batteries	General Electric Space Tech Center
• Electric Propulsion System	Hughes Research Laboratory and Hughes Space Systems Division
• Solar array/capacitor detector assembly	General Electric

4.1.4 IMPLEMENTATION

4.1.4.1 Work Breakdown Structure

The Work Breakdown Structure (WBS) for this project is shown in Figure 3. This WBS shall be updated and expanded to lower levels during Phases B and C.

4.1.4.2 Project Organization for Phases C and D

Figure 5 is a Representative Project Organization Chart for Phases C and D. For additional details refer to the organization charts for Engineering (Figure 7, page 49), Manufacturing (Figure 11, page 64), Test (Figure 19, page 88), Ground Support Equipment (Figure 22, page 96) and Facilities (Figure 24, page 106).

4.1.4.3 Schedule and Milestones

The Preliminary Program Development Schedule (PDS) is also the Master SEP Program Schedule for this project, and is shown in Figure 4, page 27. This PDS was prepared in an iterative manner with the schedules in the subsidiary program plans (Engineering Development, Manufacturing, Test, etc.) and the Electric Propulsion System Hardware Schedule. The PDS shall be updated during subsequent phases of the SEP Asteriod Belt Mission Program.

4.1.4.4 Manpower Requirements

Estimated Manpower Loading Requirements for Phases B, C, and D are shown in Figure 28, page 125.

4.1.4.5 Interfaces with Other Plans

This Project Management Plan was prepared in an integrated manner with the other subsidiary program plans. It shall be updated and implemented on the basis of thorough integration with all functional activities.

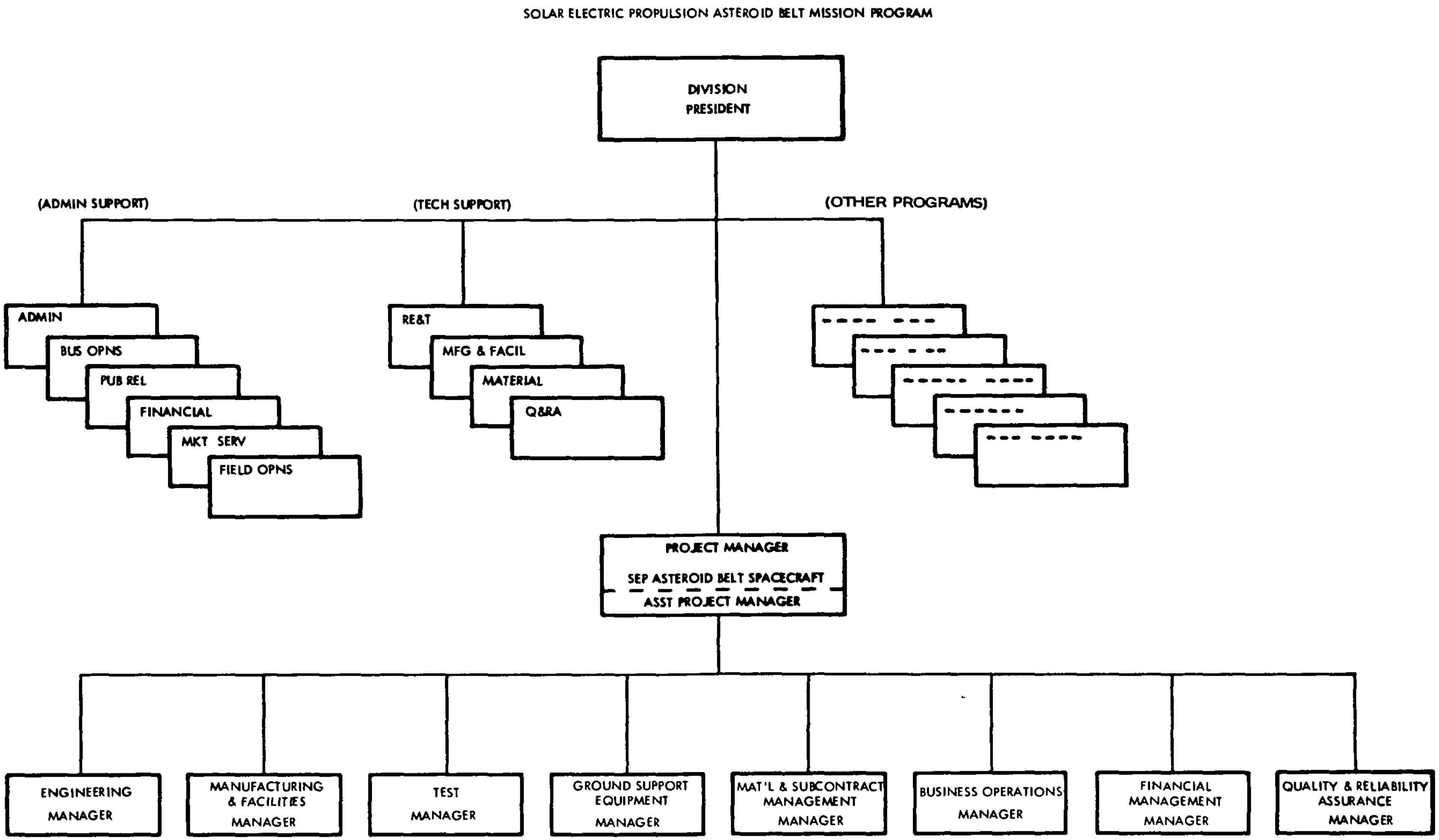

Figure 5. Representative Project Organization Chart for Phases C and D

4.2 ENGINEERING DEVELOPMENT PLAN

4.2.1 PURPOSE

The Engineering Development Plan (EDP) summarizes the orderly progression of engineering activities required for conducting the Solar Electric Propulsion Asteroid Belt Mission Program. The EDP also serves as the basis for engineering planning, organizing, staffing, directing, and controlling activities to achieve the objectives of the program in an efficient and effective manner.

4.2.2 SCOPE

The EDP spans the engineering activities of definition of system performance and configuration requirements. preliminary design definition, and design completion and verification. Continuous engineering planning and control is maintained through all phases.

4.2.3 TASK DESCRIPTIONS

4.2.3.1 Task Summary

The Program Engineering Process (Figure 6) includes the technical functions required to fulfill the engineering commitments in the developed program. Activities have been organized into the basic modules: Requirements Definition, Planning and Control, Design and Integration, and Verification.

4.2.3.2 Detailed Task Descriptions

Requirements Definition

Program Functions - Establish the approach for effective integration of engineering effort in developing, testing, supporting, and maintaining the system.

System Functions - Portray graphically and sequentially all detailed functions which must be satisfied by system elements in order to meet total system requirements; select and investigate alternative functions which offer significant benefit.

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Figure 6. Program Engineering Process

Program Requirements - Establish the manner in which contractor resources and experience will be applied to satisfy the objectives and tasks in the statements of work.

Mission Operations Requirements - Identify those operations requirements to be satisfied by a combination of system elements; obtain parameters of design, design constraints, and system effectiveness factors; establish mission guidelines, operational constraints, and reliability goals; prepare and review plans and procedures for electric thruster programming, and for navigation during near earth and thrust phases.

Facilities Requirements - Establish requirements for use by an architectural and engineering organization to design and develop/modify system facilities.

System Activation Requirements - Identify activation requirements (including transportation, assembly, installation and checkout) to be satisfied by a combination of system elements; obtain parameters of design, design constraints, and system effectiveness factors.

Preliminary Design - Support the determination of an approach to system design; support establishment of the initial System Requirements Baseline.

System End Items - Identify those system elements (equipment) required for system operations, logistics, activation, and test. Provide End Item Equipment Lists.

System Requirements - Identify and control interface requirements including launch vehicle-spacecraft, experiment-spacecraft subsystems, and spacecraft-support equipment; identify feedback changes to operations functions, design requirements for the operations functions, and to the System Specification; establish compatibility between system plans.

Planning and Control

Engineering Program - Identify the tasks and align them to program milestones and production schedules; provide the detail planning which contributes to further definition of the master schedule; provide inputs to the Program Management Networks.

Engineering Planning - Establish compatibility and consistency between schedules, budget breakdowns and work packages; provide an adequate and clearly defined interface with the Program Planning and Control function.

Engineering Cost and Schedule Positions - Determine current positions which when compared to planned positions will provide cost and schedule status; and provide cost and schedule position information which can be used as a basis for effective corrective action, if required. This effort is performed throughout the engineering life of the program.

Design and Integration

Preliminary Detail Design - Translate "design-to" requirements into "build-to" requirements; identify detailed constraints and additional design requirements applicable to production and maintenance effort; determine the design approach; conduct synthesis of alternate approaches. Tradeoff studies will be selected to concentrate engineering resources at areas of highest potential program benefit.

Detail Facility Concepts - Provide data to translate facility design requirements into facility end items; identify requirements for Real Property Installed Equipment, identify facility interfaces with other system elements and other systems.

Interface Control Concepts - Determine the basis for negotiating interface responsibilities; identify related interface requirements pertaining to cost and schedule controls; identify requirements subject to coordination between and concurrence by each of those responsible for the interfacing items.

Detail Maintenance Requirements - Assure that maintenance implications are considered in depth prior to further preliminary design of operations equipment and facilities; identify additional requirements for facilities, equipment, personnel, and procedural data.

Preliminary Detail Design - Further define interface requirements; identify feedback changes to related design requirements; establish design approach consistency.

Interface Control - Assure physical, functional, and procedural compatibility between interfacing equipment/facilities; establish customer/contractor/subcontractor responsibilities for external interfaces; establish organizational responsibilities for internal interfaces. Requirements for interface control will be identified and transmitted to JPL.

Detail Design - Create the configurations which satisfy the "design-to" requirements to derive the design solutions in accordance with the approved design approach.

Detail Design - Assure compatibility between and within equipment end items including launch vehicle-spacecraft, experiment-spacecraft subsystem, and spacecraft-support equipment; identify additional feedback changes to system functions and design requirements; further refine interface definition; derive maximum benefits from development testing.

Production Release - Provide production drawings and specifications for initial design configurations; establish the initial "build-to" baseline for individual end items.

Verification

Engineering Breadboard and Mockup Operations - Conduct for the purposes of: (1) verification of design configurations, interface considerations, equipment installation locations, and clearances; (2) aiding in the manufacture of cable harnesses; and (3) supporting design reviews by customer personnel.

Test Program - Verify the integrity of designs under both static and dynamic conditions; assure qualification requirements are satisfied; assure achievement of reliability goals; determine suitability of design configurations physically, functionally, and procedurally; verify selected materials and processes.

Logistics and Activation Operations - Provide engineering assistance during transport, installation, and checkout of equipment and procedural data.

System Test Program - Review system verification test plans and procedures. Provide engineering assistance during complete-system operational testing and assure efficient feedback of test results for technical evaluation.

Technical Performance Measurement - Plan and execute a technical performance measurement (TPM) effort as a part of the planned technical program. TPM will constitute the assessment and validation portion of the design, development, test and evaluation program for the system and its elements. TPM will include all efforts to compare performance, physical characteristics and figure(s) of merit being achieved by the contractor with the allocated and contractually required values.

System Performance Evaluation - Prepare tolerance model to allocate performance accuracies to system and subsystem elements. Evaluate variations between system performance requirements and actual performance measurements to determine potential impacts on system operations and capabilities.

Product Performance Evaluation - Evaluate variations between end item or component performance requirements and actual performance measurements to determine potential impacts on product operations and capabilities.

System Cost Effectiveness Evaluation - Evaluations shall be conducted to provide the optimum combination of system elements to meet the objectives and support requirements in terms of system effectiveness.

4.2.3.3 Associated Activities

The EDP, when fully expanded during Phase C, shall include coverage of the following and possibly additional, essential activities:

Reliability Program Plan

The Reliability Program Plan will be the master planning and control document for the reliability program for development of the Solar Electric Propulsion Spacecraft. It shall include a detailed, time-phased description of all tasks to be performed and the procedures for implementing, monitoring, and controlling these tasks. The document shall follow the outline and intent of NPC 250-1. The plan shall include the following significant tasks, as applicable:

1. Reliability Program Management
2. Reliability Analysis
3. Specification Evaluation
4. Test Planning
5. Supplier Reliability Program Management
6. Failure Analysis
7. Reliability Program Reviews

Change Control

The Program Engineering Process provides for engineering interfaces with the Configuration Management Process. Engineering will prepare the Engineering Design Change (objectives, reasons, technical descriptions, rationale, effectivity, etc.) and the Item Change Analysis (documentation affected, task description, impacts, schedule and budget requirements, etc.) for subsequent presentation to a formal Configuration Control Board.

System Safety Plan

This plan will identify the tasks that will be performed throughout the program to assure the application of system safety principles. The basic methods and techniques to be used to attain the objectives will be described. The plan will follow the guidelines set forth in the contract. System Safety will be a prime consideration in all requirements, design, and product reviews, as well as in all performance evaluations, where applicable.

Value Engineering

Contractor-developed techniques and methods will be used to enhance design quality and cost effectiveness throughout all phases of the program. The objective is the achievement of the overall requirements of performance, reliability, producibility, maintainability, and quality at the lowest total cost commensurate with schedule requirements.

4.2.4 IMPLEMENTATION AND MANAGEMENT

4.2.4.1 Program Engineering Process

The Program Engineering Process (PEP) developed at NR Space Division can provide a complete engineering response to customer requirements in an efficient and orderly manner. This facilitates the expenditure of carefully proportioned resources during Phase C in order to realize minimum development, production, and operational costs later in the program.

In tailoring the PEP to the SEP program (Figure 6 and task descriptions) for Phases B, C, and D, a major consideration will be its cost-effective application. Therefore, a minimum of documentation will be adequate for clearly recording engineering decisions so that traceability of design solutions to basic JPL requirements will be provided.

4.2.4.2 Organization

Figure 7 is a representative Engineering Organization Chart for Phases C and D.

4.2.4.3 Schedule and Milestones

Task Summary Schedule and Major Milestones

The preliminary Engineering Development Schedule for the tasks identified in Section 4.2.3 is presented in Figure 8.

Formal Reviews

Technical and administrative assistance shall be provided by contractor Engineering in support of scheduled JPL/contractor formal reviews. These reviews include:

System Requirements Review - A technical review of the requirements documented in the system specification, which specify: the performance characteristics, definition, and operability of the system; system design and construction standards, requirements for system testing.

System Design Review - A technical review of the system design approach undertaken as the design solution to the system requirements.

Preliminary Design Review - A review of the preliminary design of system end items to establish system compatibility of design, identify specific engineering documentation, and define physical and functional interface relationships between a contract end item (configuration item) and other system equipment or facilities.

Critical Design Review - A technical review of design which is accomplished to identify specific engineering documentation for release to manufacturing and to establish a basis for provisioning spares, preparation of technical manuals, and other supporting activities dependent upon a detail design definition of a contract end item (configuration item).

First-Article Configuration Inspection (Configuration Audit) - A formal audit of the "as-built" configuration of a contract end item (configuration item) against its technical documentation to establish the product configuration baseline for the CEI. Included is formal approval of Part II of the CEI detail specification (product specification).

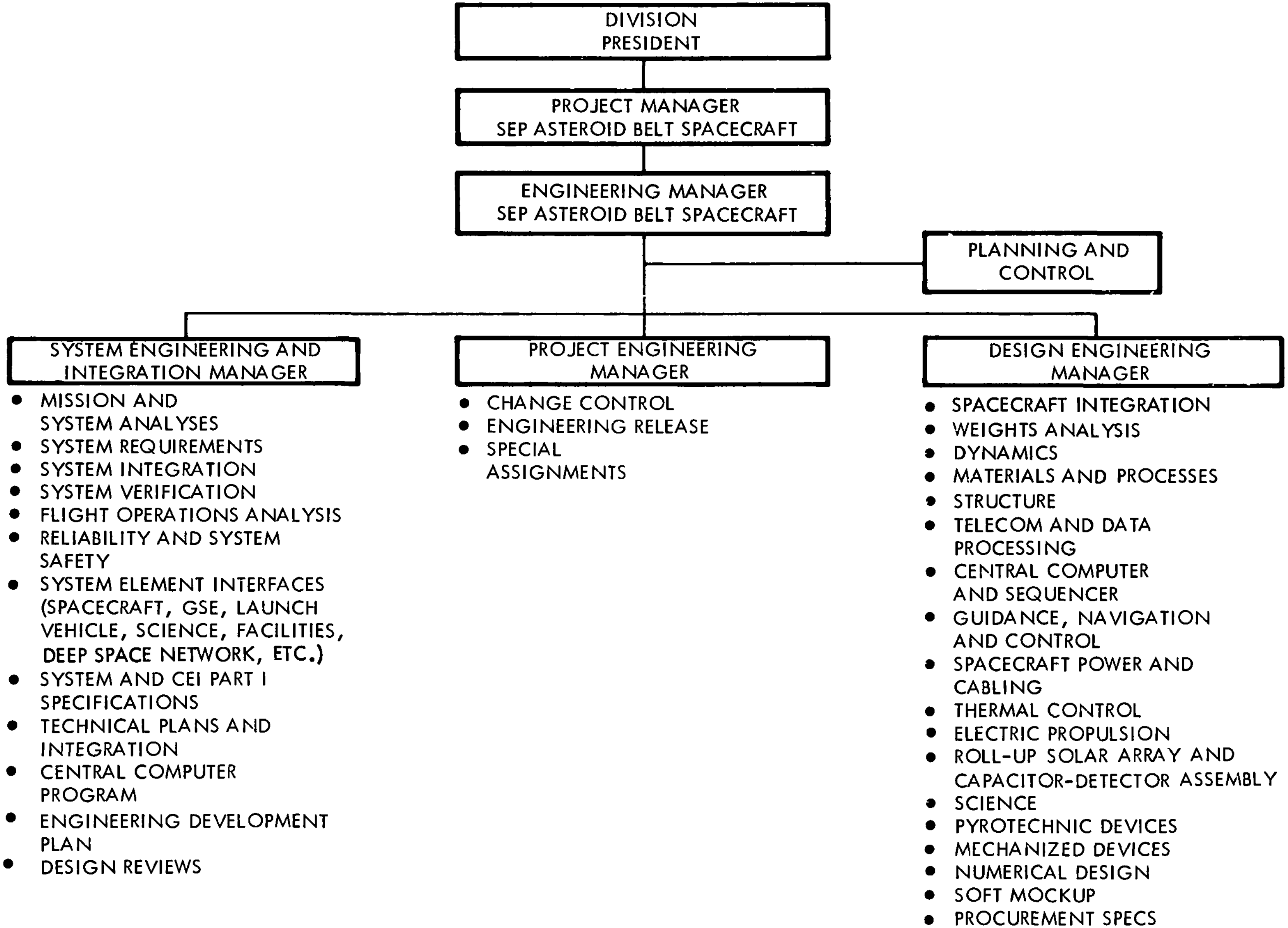

Figure 7. Engineering Organization Chart

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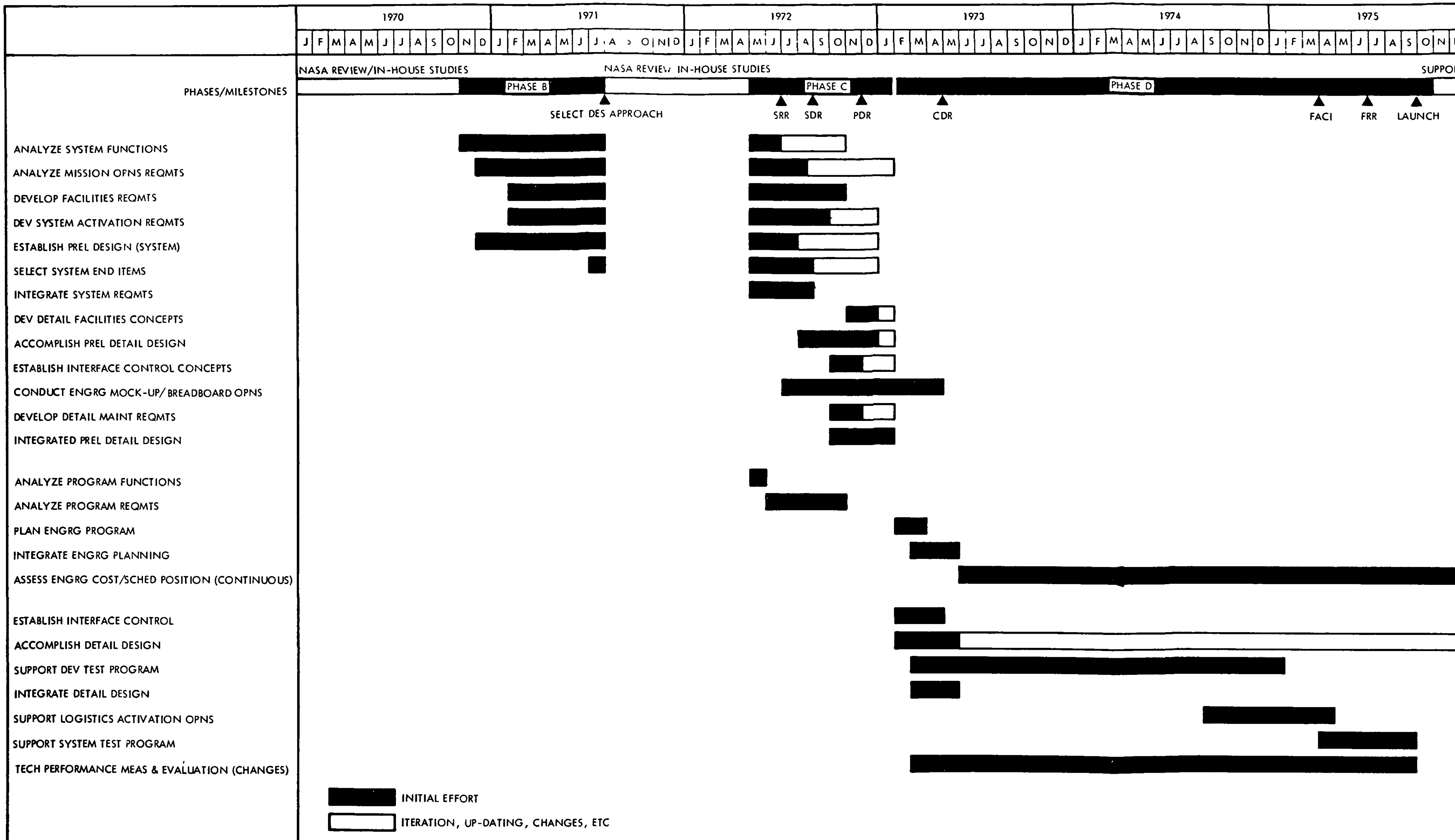

Figure 8. Preliminary Engineering Development Schedule

Flight Readiness Review - A formal review of action items to verify completion of satisfactory solutions to previously identified problems having a detrimental impact on launch or mission capability.

4.2.4.4 Interfaces with Other Plans

The EDP shall be compatible with other contractor program plans.

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4.3 MANUFACTURING PLAN

4.3.1 PURPOSE

The Manufacturing Plan summarizes the planned orderly progression of manufacturing activities for conducting Phases B (Definition), C (Design), and D (Development/Operations) of the Solar Electric Propulsion (SEP) Asteroid Belt Mission Program.

The objective is to identify and define the manufacturing functions which, when implemented as a coordinated element of the total program, will result in maximum confidence and assurance that the SEP spacecraft will perform in accordance with mission criteria.

4.3.2 SCOPE

This plan presents the initial manufacturing approach for the fabrication, qualification, checkout and acceptance of the SEP flight spacecraft, test and qualification spacecraft, and support equipment. It covers the manufacturing activities through all program phases and has been tailored to meet the specific requirements of the SEP Asteroid Belt Mission Program.

This plan will be expanded to levels of greater detail during Phase B and finalized during Phase C.

4.3.3 TASK DESCRIPTIONS

4.3.3.1 Requirements

The major items of hardware selected during the current contract for accomplishing the objectives of the SEP Asteroid Belt Mission Program consist of one soft mockup, one structural test article, one development test spacecraft, one qualification test spacecraft, and one or two flight spacecraft. Based upon these requirements, manufacturing tasks have been developed to establish the manner in which manufacturing resources and experience shall be applied to satisfy program objectives.

4.3.3.2 Rationale for Selecting Tasks and Defining Scope

Extensive manufacturing technology and experience has been gained by NR from past and present aerospace programs. This has resulted in the

unique capability to define and implement effective manufacturing systems. This capability has been applied in determining and analyzing the specific manufacturing requirements of the SEP Asteroid Belt Mission Program.

4.3.3.3 Task Summary

For simplicity the activities required to fulfill the manufacturing commitments in the development of the SEP program have been separated into major tasks. Related activities have been organized into the basic modules identified below.

Mockup Fabrication

Spacecraft Fabrication

Test Article Fabrication

Support Equipment Fabrication

Manufacturing Engineering

Production Control

4.3.3.4 Detailed Task Descriptions

Mockup Fabrication

A full-scale soft mockup shall be fabricated during Phase C for purposes of (1) verification of design configurations, interface considerations, equipment installation locations, and clearances; (2) aid in the manufacture of tubing and wire harnesses; (3) supporting design reviews by customer personnel.

The mockup will be fabricated by the Engineering Support Model Shop from aluminum alloy sheet metal, angles, and extrusions.

Spacecraft Fabrication

The main spacecraft structure evolved during this study contract comprises three major structural assemblies, as shown in Figure 9. These are identified as the Science section, Equipment Compartment section, and the Electric Engine section.

The primary structure of all sections consists of L-shaped aluminum alloy extrusions with a secondary structure of T-shaped aluminum alloy

Figure 9. Manufacturing Breakdown - Solar Electric Propulsion Spacecraft Design

extrusions. The Equipment section, with the exception of the side normally away from the sun, is enclosed by sheet metal panels. The shade side contains bi-metallic louvers for thermal control. The Equipment Compartment Section and Electric Propulsion Power Conditioning Equipment are protected with meteoroid shielding of the bumper type and screen type. Details and assemblies are joined by mechanical fasteners.

Provisions are included for installation of science experiments, telecommunications and data processing equipment, central computer and sequencer equipment, guidance, navigation and control equipment, spacecraft power and cabling, thermal control (i.e., insulation, bi-metallic louvers, surface coatings, etc.), electric propulsion system, solar panels, science experiments, pyrotechnic devices, and mechanized devices.

There is also a spacecraft booster adapter assembly consisting of conventional aircraft aluminum alloy skin and stringers.

Detail fabrication consisting of sheet metal, extrusions, and machined parts shall be accomplished within established shop departments utilizing existing equipment to the greatest extent possible with tooling requirements kept to a minimum.

Fabrication and mating of the structural assemblies shall be performed in a precision assembly shop department using the special tooling described later in this plan.

System and equipment installations, noted above, shall be accomplished in an environmentally controlled area. Manufacturing testing and checkout shall be conducted progressively to Design Checkout Specifications (DCS) to verify electrical, mechanical, and electromechanical subsystems and assemblies. An analysis of system and equipment specifications shall be initiated during Phase B and analyzed in depth during Phase C to define the manufacturing complexity and determine subsystem assembly, test, and checkout requirements. Contractor manufacturing time spans and supplier and/or subcontractor subsystem delivery schedules shall be established accordingly.

Test Article Fabrication

Structural assemblies for the structural test article, development test spacecraft, and qualification test spacecraft shall be fabricated in Phase D using flight spacecraft details and tooling. Systems and equipment installations on the development test spacecraft shall be sufficient for weight and balance, vibro-acoustic, EMI/RFI, and thermal balance tests. Additional installations and tests shall be conducted as necessary to verify design parameters. The qualification spacecraft shall be sufficiently complete for 100 percent flight qualification.

Support Equipment Fabrication

There are two types of support equipment. Nondeliverable support equipment consists of Special Tooling, Special Test Equipment (STE), and Material Handling and Parts Protection equipment (MH/PP). Deliverable support equipment consists of Ground Support Equipment (GSE).

Special Tooling. Detail tools, templates and assembly drill jigs shall be fabricated for the assembly and mating of the three major spacecraft sections and the spacecraft booster adapter assembly. Control tools shall be fabricated for controlling the interface of (1) the SEP engine and power conditioning panel with the spacecraft, (2) the solar array panels with the spacecraft, and (3) the spacecraft to the launch vehicle. Preliminary plans for their manufacture and use shall be established during Phase B. Tooling lists, concepts, bar charts, and schedules shall be finalized and implemented during Phases C and D.

Special Test Equipment. Tool and gage crib test equipment, and existing STE designed and fabricated for other programs shall be used where applicable. Additional STE requirements for verifying electrical, mechanical, and electromechanical assemblies and systems shall be determined by STE engineering during Phase C.

Material Handling and Parts Protection. MH/PP equipment includes slings, dollies, work platforms, racks, and protection devices required to efficiently handle and protect the SEP structures and systems through all phases of fabrication, assembly, installation, and test operations. Special care shall be given to the handling of the roll-out solar array subassembly units.

Ground Support Equipment. Requirements for GSE, determined by Engineering, will be negotiated as deliverable contractual end items. Manufacturing shall utilize established procedures and existing facilities for fabrication and assembly. GSE will be used during the fabrication and testing cycles and shall be delivered with the spacecraft in order to minimize program costs.

Manufacturing Engineering

The Manufacturing Engineering organization shall provide manufacturing producibility, tool engineering, special test equipment engineering, manufacturing methods, tool planning, manufacturing order planning, and shop contact. This technical support shall be provided to manufacturing departments responsible for the fabrication, assembly, installation, and testing of the SEP flight spacecraft and GSE equipment.

Manufacturing Producibility. Manufacturing Engineers shall serve as producibility consultants to Design Engineering during Phases B and C to provide analysis of designs from a fabrication and tooling feasibility viewpoint and also to recommend the optimum practical approach for facilitating machining, forming and processing.

Tool Engineering. Tool Engineers shall develop the basic manufacturing operational flow and major tooling concepts as the engineering design is developed. Block flow diagrams, manufacturing task breakdown sketches, and major tooling bar charts shall be prepared for management visibility and the use and guidelines of scheduling, planning, and manufacturing personnel. Tool Engineers shall preprogram the long-lead tool requirements to advance engineering drawings and monitor tool design and fabrication to assure compliance with program requirements. A minimum cost approach can be applied in determining all tooling requirements due to the low production nature of the SEP Asteroid Belt Mission spacecraft program.

Tool Design. Tool Design personnel shall translate Engineering design criteria into tool designs to assure the dimensional and operational integrity of contract end items.

Special Test Equipment Engineering. Subsystem analysis shall be performed by Manufacturing Engineers to establish test sequence logic, and determine availability of existing test equipment. They shall prepare test logic flow plan drawings for manufacturing and determine STE and Design Checkout Specification (DCS) requirements.

Production Control

Regulation of manufacturing activities in accordance with program objectives is established and monitored by this function.

Programming and Scheduling. Master programming/scheduling charts depicting long leadtime procurement requirements shall be prepared during Phase C. Also during Phase C, a master manufacturing development schedule shall be prepared to depict a coordinated plan for the fabrication of the mockup, test articles, and flight spacecraft. A preliminary first flight spacecraft schedule is shown in Figure 10.

Control Systems. Various systems are available to control or monitor manufacturing activities and furnish management and customer with accurate data and program visibility. Manufacturing Data Retrieval (MADRE), and Production Order Location and Report system (POLAR) are two of these which will be implemented in Phase D.

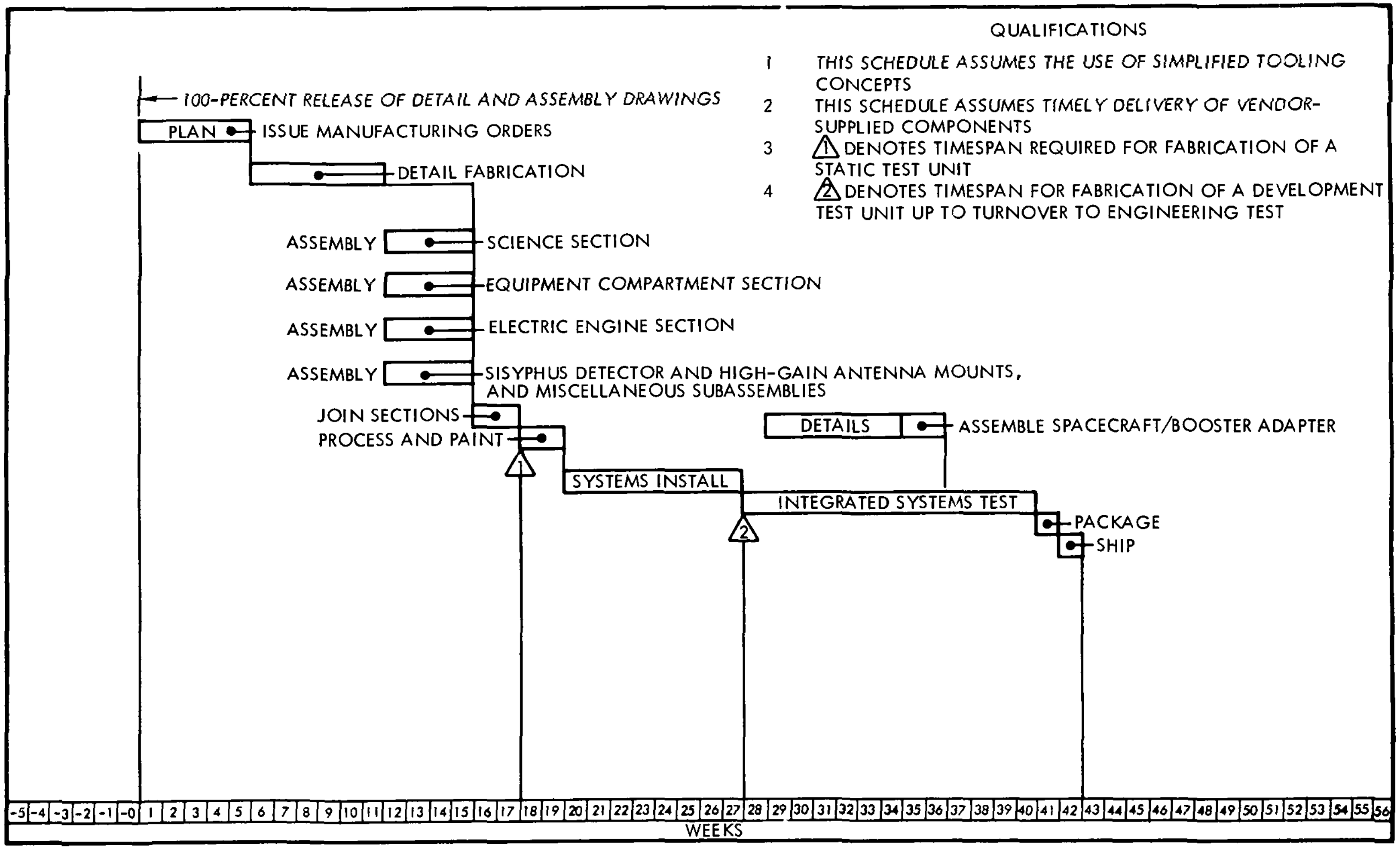

Figure 10. Preliminary Manufacturing First-Flight Spacecraft Schedule

4.3.4 IMPLEMENTATION AND MANAGEMENT

4.3.4.1 Organization

A Manufacturing and Facilities Manager shall be appointed at the beginning of Phase B. He shall direct all activities through a project-type organization. He shall report directly to the Spacecraft Project Manager. Figure 11 illustrates the organization structure and reporting channels.

4.3.4.2 Task Summary Schedule and Major Milestones

The preliminary manufacturing task summary schedule and major milestones are illustrated in Figure 12. This shall be refined during Phase B and finalized in Phase C.

4.3.4.3 Cost Avoidance

The manufacturing system has been developed at NR Space Division to provide a careful balance of effort in order to realize minimum cost for development, production, operations, and maintenance.

Cost-effectiveness shall be a major consideration of the manufacturing feasibility evaluation which shall be conducted during Phases B and C as "design-to requirements" are translated to "build-to requirements."

4.3.4.4 Interface Requirements

Interface coordination with all program plans which comprise the Program Development Plan shall be conducted in greater detail as the program evolves.

Interface liaison requirements with subcontractors shall be established when "design-to requirements" have been finalized to assure complete coordination and compatibility of the manufacturing effort.

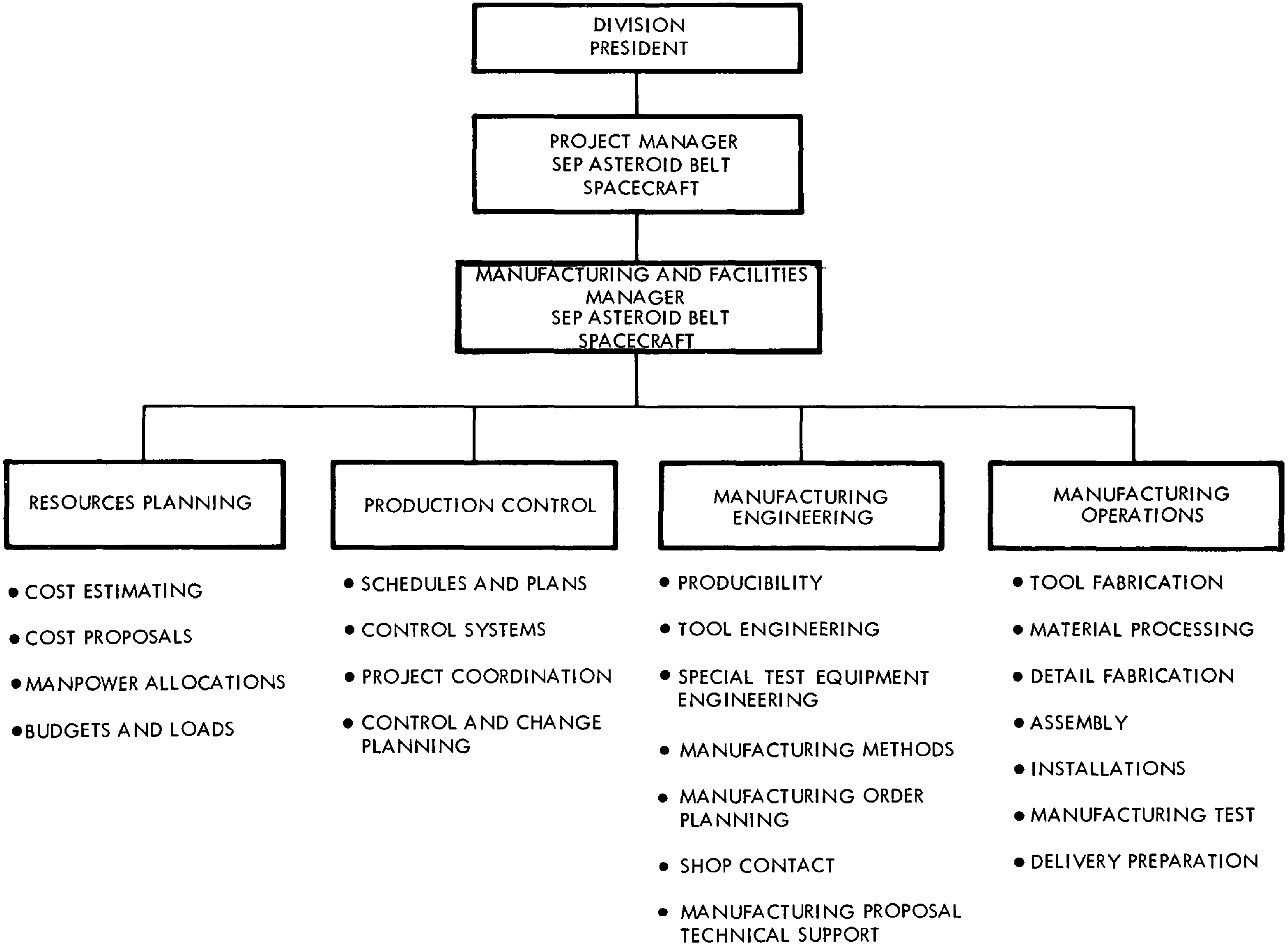

Figure 11. Manufacturing Organization Chart

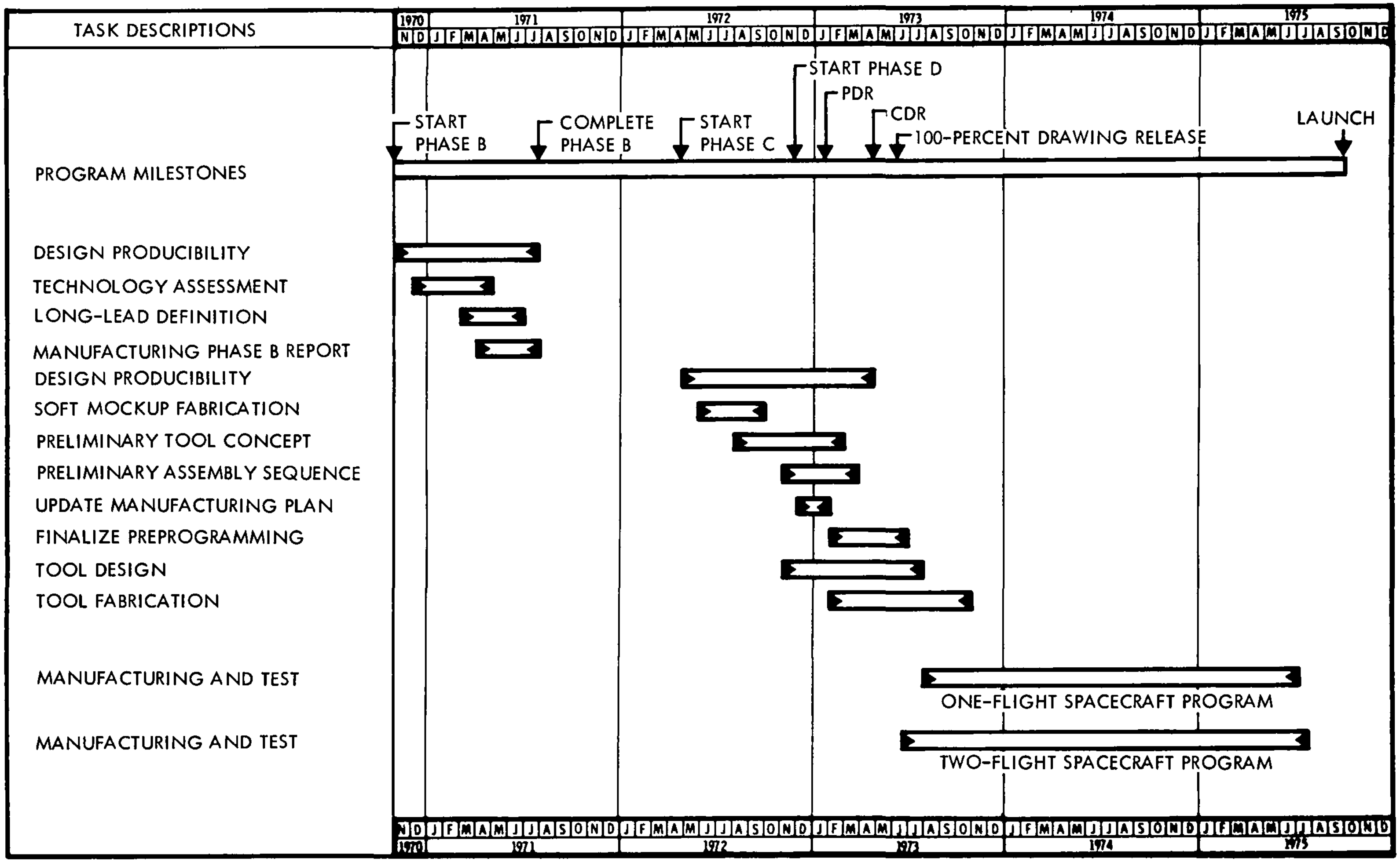

Figure 12. Preliminary Manufacturing Task Summary Schedule

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4.4 PROGRAM TEST PLAN

4.4.1 PURPOSE

The function of the Program Test Plan, as an element of the Program Development Plan, is to define the test activities required for development, qualification, and acceptance of spacecraft hardware and software, and for the planned development testing of spacecraft subsystems.

A primary objective of the Program Test Plan is to define the test approach, and test requirements necessary to develop and qualify hardware which will provide for launch survival, solar panel and equipment deployment, propulsion system start-up and stability, spacecraft dynamics, controllability, durability, compatibility, and data return for a successful asteroid belt mission.

4.4.2 SCOPE

The Program Test Plan describes the planning (Phases B and C) and testing (Phase D) to be conducted for the Solar Electric Propulsion (SEP) Asteroid Belt Mission Program. The plan covers the test program for both one- and two-flight spacecraft programs. The second vehicle in the two-flight spacecraft program would be available for backup. The plan specifies requirements regarding types of tests, test articles, and test facilities.

The tests to be performed are categorized in the following paragraphs.

4.4.2.1 Static Structural Tests

Static structural tests are those tests performed on flight structures to determine the feasibility of the design approach with regard to maximum boost loads and maximum bending moments.

4.4.2.2 Developmental Tests

Developmental tests are defined as those functional and environmental tests designed to verify the performance of the test article, with the following objectives:

1. Determine the feasibility of design approach.

2. Evaluate hardware performance under simulated or actual operational environments on representative samples.

3. Establish and evaluate test program software and controls.

4. Develop ground operations concepts for checkout.

5. Determine design readiness for Qualification testing.

4.4.2.3 Qualification Tests

Qualification tests are performed to verify design adequacy of the test article. The tests are designed to evaluate the system design environmental performance of handling, shipment, launch, and mission.

Qualification tests will be accomplished by the Supplier and Subcontractor to the subsystem level, where possible, and by the Spacecraft Contractor to the total spacecraft system level, using formal, approved procedures. Where qualification testing is accomplished by a supplier or subcontractor, the tests will be witnessed by spacecraft contractor subsystem specialist and/or inspection personnel.

Qualification of the spacecraft will be accomplished through subsystems, combined systems, and integrated systems tests conducted upon representative samples of all spacecraft subsystems, GSE, and software.

4.4.2.4 Reliability Development

Consistent with Phase A conceptual design definition of subsystems, Reliability aspects have not been incorporated into this Test Plan. However, it is recognized that Reliability considerations are important to the program; therefore, the subject is mentioned briefly here for continuity.

4.4.2.5 Acceptance Tests

Acceptance tests are performed on all flight and spares hardware to establish that each deliverable item conforms to design configuration and end item performance specification, and to disclose workmanship defects.

4.4.3 TASK DESCRIPTIONS

4.4.3.1 Test Approach

The approach used for arriving at specific tasks provides a basis for the establishment of an orderly progression of tests which can achieve the proper balance of effort and resources. A key element in the Program Test Plan is a Program Test Network, Figure 13, which provides the overall test program logic for the SEP Spacecraft Test Program Elements shown in Figure 14.

A major goal of the Test Program is the attainment of the highest confidence levels, at minimum cost, within the program schedule. To achieve this goal, it is required that the development test hardware be kept to the minimum compatible with schedule requirements; that existing qualification data for proven systems concepts and components be used wherever possible, that development and qualification hardware be used for Reliability verification wherever necessary, and that acceptance testing be performed at the highest assembly level practical. Experience and test technology developed in previous unmanned spacecraft programs will be utilized to the maximum extent possible in order to minimize development time and the associated costs.

4.4.3.2 Test Requirements

Preliminary test requirements specified in the following paragraphs conform to the categories defined in Section 4.3 2: Static, Development, Qualification, Reliability, and Acceptance. This plan covers each category in general terms. Separate, coordinated plans to the detail required for each category will be developed in succeeding program phases.

Static Structural Tests

Purpose. Static structural tests are to determine the feasibility of the design approach with regard to strength of the primary and secondary flight structures under loads of boost acceleration and bending moments.

Test-Article Description (Table 1). Static structural tests will utilize a test article consisting of primary and secondary flight structures, including equipment bay structure and bracketry, solar panel support structure, high and low gain antenna boom supports, electric propulsion system housing structure, and component attach fittings. Mass and location of significant components will be simulated and mounted to the structure.

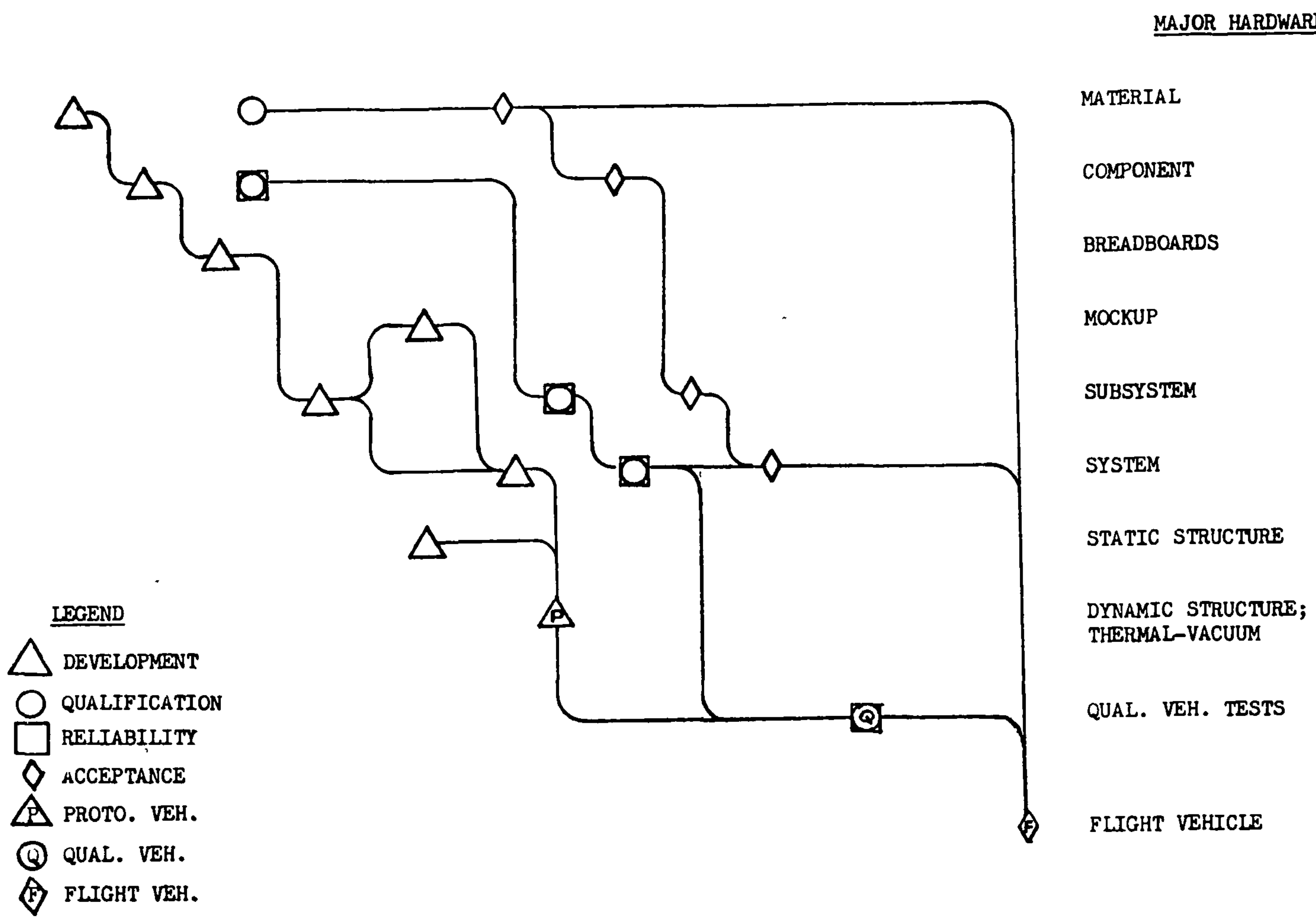

Figure 13. Program Test Network

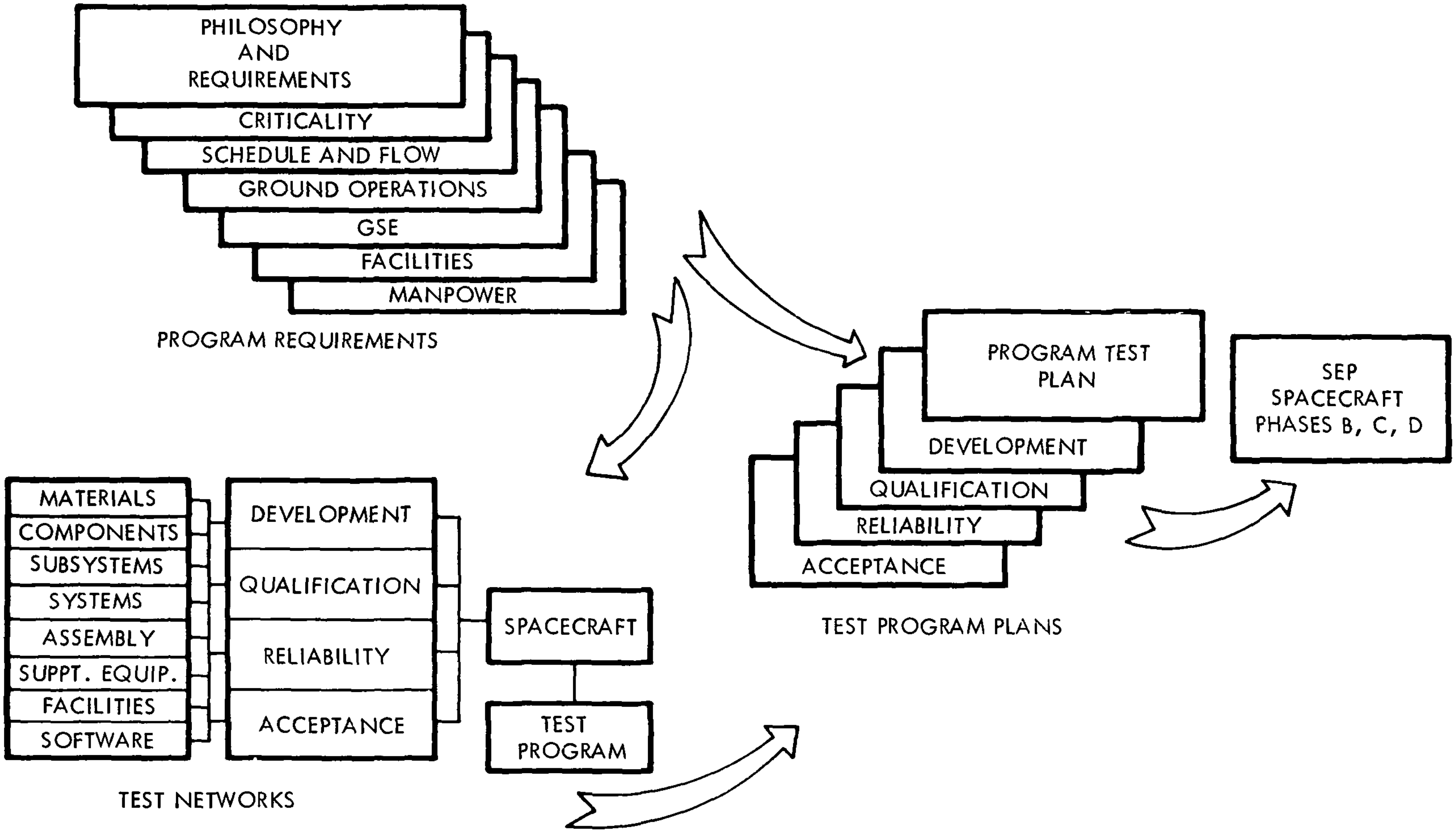

Figure 14. SEP Spacecraft Test Program Elements

Table 1. Test Articles Requirements Summary

This summary represents a minimum number of test articles needed to satisfy the requirements for development, qualification, and acceptance of a flight quality solar electric spacecraft.	
Test Article	Remarks
Breadboards	As required by Design Engineering to develop subsystem electrical, mechanical, and thermal characteristics
Structural static test article	Required for design verification of primary and secondary structure static loads
Development test spacecraft	Required for early investigation and design verification of dynamic loads, EMI/RFI, and thermal balance
Qualification test spacecraft	Required to verify that spacecraft subsystems will perform as an integrated system and will meet functional and environmental performance requirements.

Test Description. Static loads simulating maximum acceleration loads, and maximum bending moments will be applied through the spacecraft adapter interface and component attach fittings. Strain, load, and deflection data will be recorded. A flow diagram for Static Structural tests is given in Figure 15.

Necessary Equipment and Facilities (Table 2). The Spacecraft Contractor will require standard Static Structural Test equipment consisting of the necessary fixture for holding the structure, wire, strain gages, load application mechanism, load and strain measurement and recording instruments, and control consoles.

A facility large enough to accommodate the fixture and structure to be tested, plus the test equipment noted above is required.

Development Tests

Purpose. Development tests are those functional and environmental tests designed to verify the performance of the test article. These tests encompass the selection and development of materials, components,

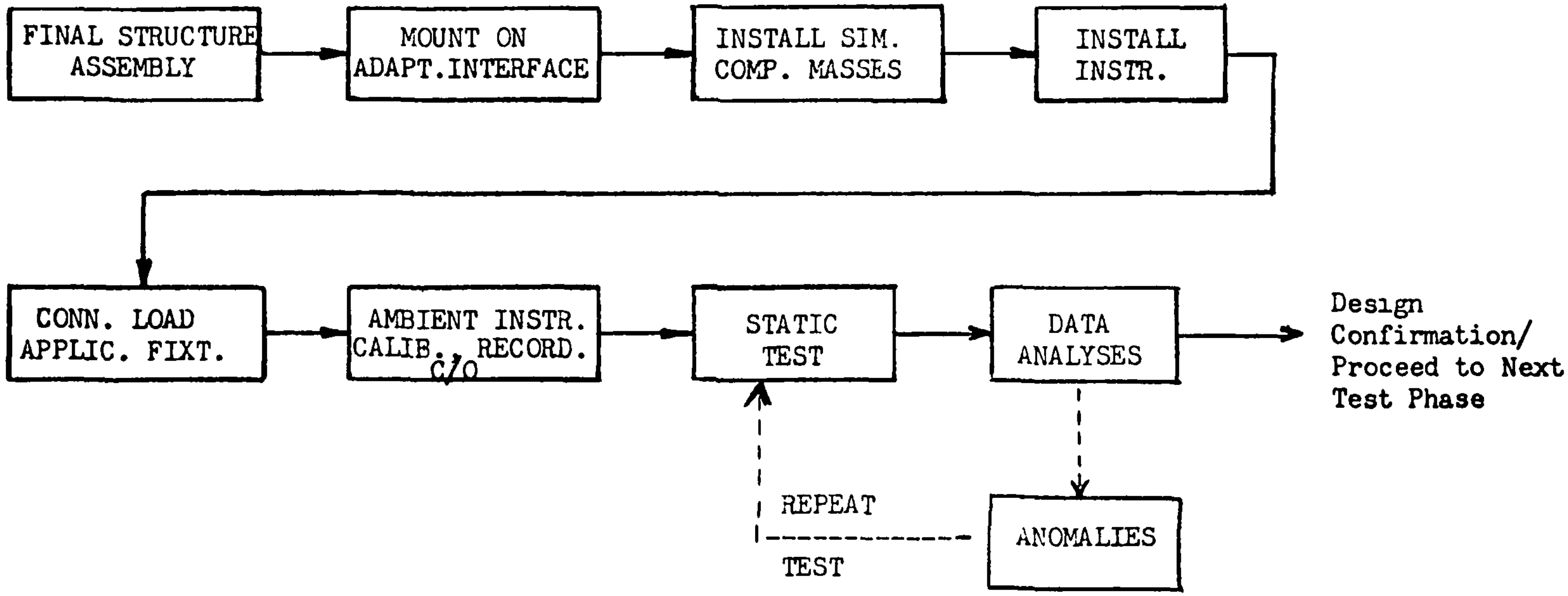

Figure 15. Static Structural Test Article Flow Diagram

Table 2. Test Facilities Requirements Summary

This summary presents the major test facilities required for Development, Qualification, Acceptance, and Prelaunch testing of a Solar Electric Spacecraft.

Item	Purpose
1.	Functional and environmental development tests of materials, components, and breadboard subsystems
2.	Static structural tests of primary and secondary flight spacecraft structure
3.	Development Spacecraft and complement of checkout equipment
4.	RF screen room for EMI/RFI testing (Development and Qualification Spacecraft)
5.	Vibration testing of Development and Flight Spacecraft
6.	Acoustic testing of Development, Qualification, and Flight Spacecraft
7.	Shock testing of Development and Qualification Spacecraft
*8.	Thermal-Vacuum testing of Development, Qualification, and Flight Spacecraft
9.	Pre-Launch checkout

*Simulated conditions:

1. Solar flux environment
   140 watts/square meter to 11.4 watts/square meter
2. Vacuum capability of 10^{-5} Torr
3. LN_2 shroud (320 F Wall Temp.)

subsystems and systems to determine the feasibility of the design approach and to determine design readinesss for qualification testing.

Where required, development testing to the subsystem level, such as the capacitor integration test with the solar array, power subsystem distribution and control, will be accomplished by the Supplier or

Subcontractor, utilizing specifications and approved procedures, and witnessed by Spacecraft Contractor Subsystem specialist and inspection personnel.

Test-Article Description (Ref. Table 1). To insure the success of the follow-on Qualification Test Program, prototypes of all subsystems will be installed in the Development Test Spacecraft. In some cases, where it is not necessary to have a full complement of components or assemblies, the masses and thermal characteristics of those components or assemblies not installed will be simulated.

Test Description. Subsequent to Static testing, tests to provide preliminary design verification in the areas of vibration, acoustics, EMI/RFI, and thermal vacuum are required early in the program.

Principal development tests to be performed will be tests of materials, components, assemblies, and subsystems which have not been developed for other programs, have greater environmental or life requirements than those previously developed, or must function in a different manner when integrated with the total system. Specific areas of concern will include attitude control with electric engines, deployment of spacecraft systems, and the central computer and sequencer. "Off-the-shelf" hardware is to be used to the greatest extent possible; therefore, development testing will be held to a minimum.

The test configuration planned for the Development Test Spacecraft is described in the Manufacturing Plan section of this report and is composed of the elements noted in the Hardware Utilization List (Table 6).

A gross test flow indicating the types of tests desired of a Development spacecraft is given in Figure 16. A "building block" approach is used whereby a gradual buildup to all systems operating together is accomplished. Initial power and grounding checks will verify proper wire paths, values, and the absence of "sneak" grounds. Subsystems will be individually operated and evaluated. Electro-mechanical devices such as antenna booms and actuators, electric thruster array translator and gimbals, extension and rotation mechanisms for solar panels, and antennas and solar panel pin pullers, will be tested for fit and function. Vibro-acoustic tests will be performed on the stowed spacecraft configuration and will simulate the launch environment of vibration and acoustics. Also planned are shock tests to simulate shock resulting from pyrotechnic separation of the spacecraft from the launch vehicle, and shock produced by antennas and solar panel pin pullers. EMI/RFI tests to determine the presence or absence of interference will be accomplished in an RF screen room. Thermal vacuum tests will be accomplished in the simulated environments of high and low

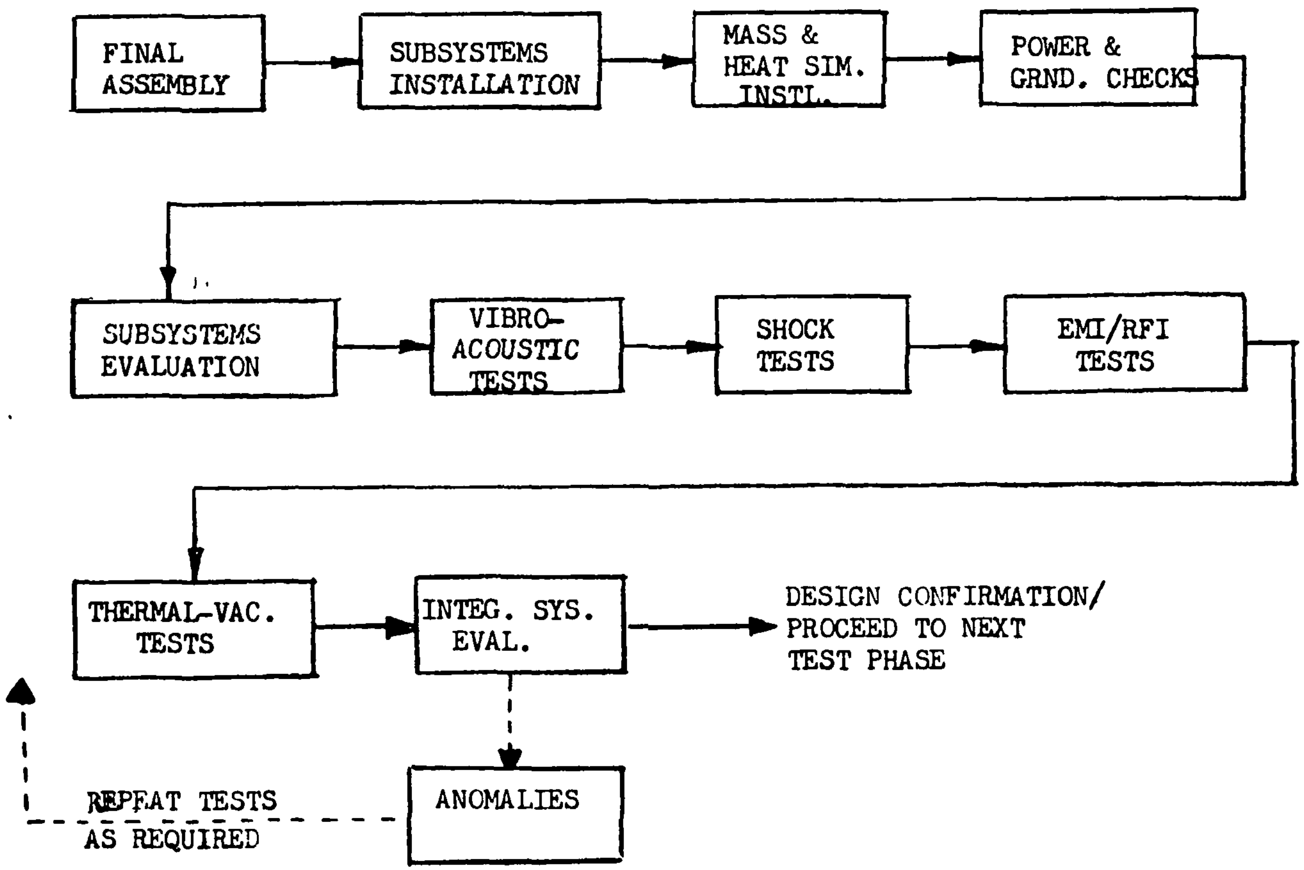

Figure 16. Development Test Spacecraft Flow Diagram

temperatures, solar flux, and vacuum upon the total spacecraft with subsystems operating in sequences to simulate the mission. Excluded from this series of tests are the Science instruments, and the extension of antennas. Following thermal-vacuum testing and evaluation, integrated systems tests will be accomplished as post-environmental checks for system degradation and as a prelude to Qualification Tests.

Necessary Equipment and Facilities (Table 2). Development testing will require that special test equipment and facilities be provided. For materials, components, and subsystems development, the Supplier or Subcontractor will be required to provide the equipment and facilities necessary.

The Spacecraft Contractor will require prototype Ground Support Equipment developed as part of the Spacecraft subsystems, in addition to facilities for·

1. Materials, components, and subsystem breadboard tests, for development of items not subcontracted, and or checks on supplied equipment
2. Development Test Spacecraft and associated support equipment for ambient conditions testing
3. RF screen room for EMI/RFI testing
4. Vibration Testing
5. Acoustic Testing
6. Shock Testing
7. Thermal-Vacuum Testing

Qualification Tests

Purpose. Qualification testing will be performed on representative samples of spacecraft subsystems, support equipment, and software. These tests will verify that the spacecraft subsystems will perform as an integrated system and will meet the functional performance requirements during or after exposure to environmental conditions equal to or more severe than conditions expected during the mission life. If a component fails during the series of qualification tests, it may be replaced by a spare which has gone through equivalent testing. The impact of such failure on qualification of the spacecraft will be evaluated at the time of failure.

Redesign or retest requirements will consider the nature of the failure, test history of the part, criticality of the failure, and other related factors.

Test-Article Description (Table 1). Qualification testing to the levels and environments indicated will require duplication, to the greatest extent possible, of a flight vehicle in launch and mission configuration except for ordnance items. The conditions imposed establish a requirement for a Qualification Test Spacecraft.

Test Description. Qualification tests to be performed will include those tests conducted by the Supplier or Subcontractor and the Spacecraft Contractor on components and subsystems of flight quality which have not been previously qualified on earlier programs for exposure to equal or more severe environments.

The determination as to level of testing is predicated on such factors as packaging, subsystem complexity, as well as environmental facility capability and availability.

Qualification of the spacecraft will be accomplished through subsystems, combined systems, and integrated systems tests conducted upon hardware which has been designed and fabricated to flight spacecraft specifications. The same general sequence of tests as that described for Development spacecraft will be employed. A full complement of subsystems with all components will be installed except for ordnance items. The spacecraft will be considered in the same light as a flight spacecraft, therefore, the procedures used for handling, and test of spacecraft and support equipment will be qualified, as well as the hardware and personnel.

Following installation of subsystems, a series of functional tests will be conducted to assure satisfactory operation prior to application of simulated environments.

Upon completion of subsystem functional tests, the spacecraft will be prepared for application of dynamic environments. The initial test will be an acoustic qualification test to confirm the structural and functional integrity of the spacecraft. Subsystems will be functionally checked prior to and following each environmental test. The spacecraft will be in the launch configuration. A possible exception is that Science payload instruments will not be installed, other than for on-off functional tests.

A separation shock test follows, in which the shock caused by firing of pyrotechnics for separation of the spacecraft from the Centaur adapter is simulated.

To confirm the absence of radio frequency or electromagnetic interference, the spacecraft will be installed in a shielded room where all electrical and electronic equipment will be operated and appropriate measurements taken to determine the spacecraft radio frequency signature for susceptibility to external RF sources, and interference generated by the spacecraft itself.

Upon completion of EMI/RFI tests, the spacecraft will be prepared for the final series of environmental qualification tests under simulated space environment. Thermal-vacuum tests will verify that subsystem performance is not degraded by exposure to space conditions of temperature and vacuum. Electric engines will not be fired and, due to possible thermal vacuum chamber size limitations, equipment such as antennas may not be installed, in which case loading and output characteristics would be simulated. Critical spacecraft qualification tests are planned for completion prior to start of flight vehicle acceptance tests. A flow diagram for Qualification tests is given in Figure 17.

Necessary Equipment and Facilities (Table 2). Qualification testing will be accomplished to the subsystem level, where possible, by the Supplier or Subcontractor who will supply the equipment and facilities necessary to perform the tests.

The Spacecraft Contractor will require a full complement of Ground Support Equipment and facilities necessary for:

1. Qualification testing of subassemblies, and subsystems as a check on Supplier or Subcontractor

2. Qualification Test Spacecraft and associated GSE for ambient conditions testing

3. RF screen room for EMI/RFI testing

4. Vibration testing

5. Acoustic testing

6. Shock testing

7. Thermal-Vacuum testing

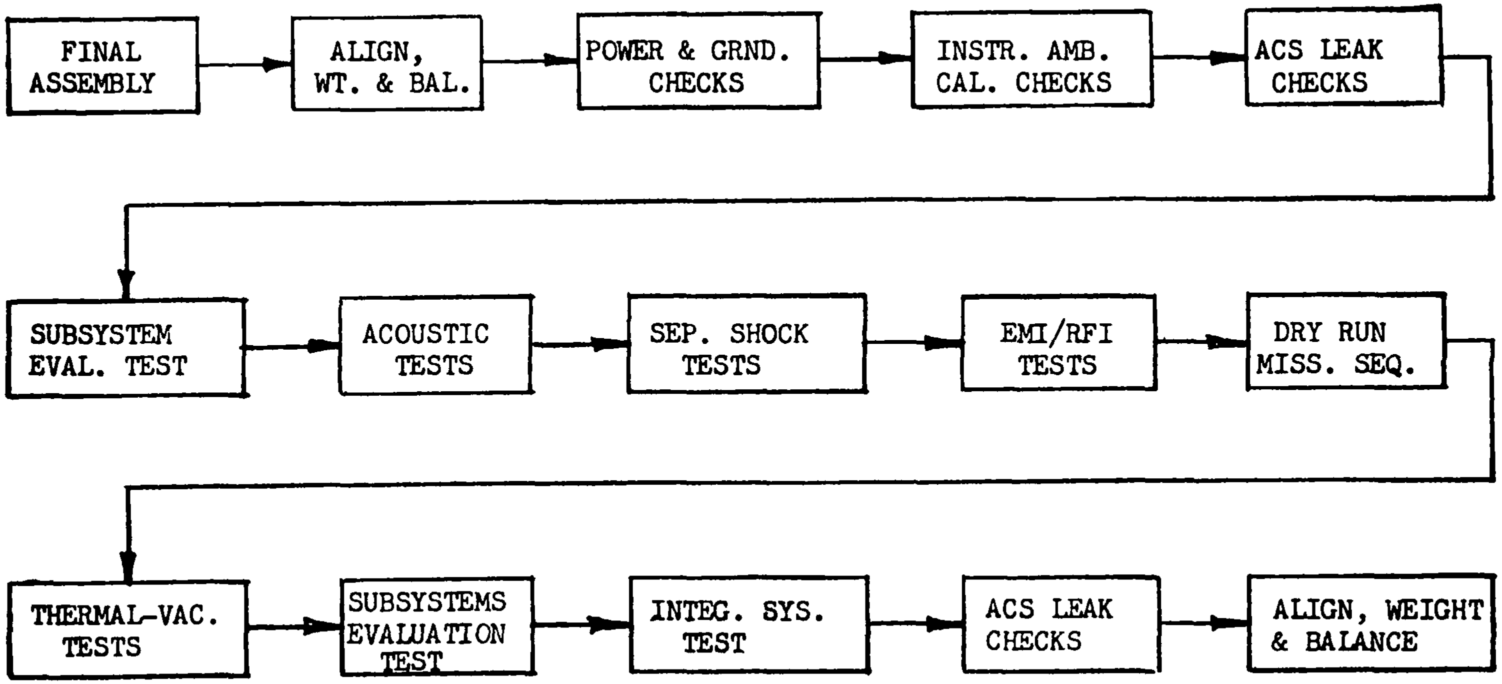

Figure 17. Qualification Test Spacecraft Flow Diagram

Reliability Development

A Reliability Assurance Program for the Solar Electric Propulsion Asteroid Belt Program will be defined during the Phase B study to provide an integrated development program. Reliability development shall be an optimal combination of analysis and or testing intended to conclusively verify, consistent with criticality requirements, that the ground and flight systems are capable of performing the mission.

The techniques to be employed and the emphasis placed on each will be predicated upon the factors of cost and schedule constraints, availability of hardware from other programs, and the ability to simulate the mission and related equipment operations in ground laboratory testing.

The major program elements pertinent to vehicle and mission reliability shall be encompassed by the Reliability Program Plan and the Integrated Reliability Test Plan that consists of a Reliability Test Development Plan and a Confidence Development Plan.

Reliability Program Plan. The Reliability Program Plan will contain the description of the reliability organization, definitive reliability objectives, associated implementation media and techniques, and documentation requirements.

Integrated Reliability Test Plan. The Integrated Reliability Test Plan will consist of two main factors. These are an integrated test plan for new equipment testing required for engineering development, and the integrating of test information acquired by previous applicable programs into the new plan.

Implementation of this integrated program will then provide continuity of pertinent elements of both development plans and a commonality of the basic mathematical media employed as a linking tool.

Confidence Development Plan. The Confidence Development Plan will encompass all necessary testing for the SEP Spacecraft Program including associated Ground Support Equipment, and will provide an integrated reliability development and verification program designed to achieve the required level of confidence for the reliability goal. Confidence growth on the program will involve the evaluation of data obtained at numerous facilities under various test conditions. Based on these evaluations, a confidence statement will be generated relating performance and reliability under anticipated mission conditions. The techniques to be utilized will permit direct quantitative evaluation of ground test and mission equivalency with the sum

total of this equivalency at all test facilities to provide the basis for the confidence evaluation.

Acceptance Tests

Purpose. As a major element of the Program Test Plan, Acceptance testing is the final phase, planned to assure delivery of SEP Spacecraft Program end items in a timely and cost effective manner with performance demonstration to specifications. Each delivered end item, in addition to being a member of a hardware family previously developed and qualified, will undergo acceptance testing to operational performance requirements within the limitations of program costs and schedules.

In order to satisfy the objective of hardware conformance to design configuration and performance specifications, a series of tests will be performed: Receiving, In-Process, and Post-Manufacturing Checkout, including Prelaunch activities. Receiving tests insure the performance capability of components or assemblies prior to their installation. In-process tests insure fabrication integrity and functional performance of hardware items, at their installation station or any subsequent end item fabrication station which could contribute to checkout sequencing and or facilitate replacement. Proof pressure tests of installed propellant and pressurant systems, and wire harness megger checks fall in this category. Post-Manufacturing tests integrate all systems and demonstrate, within facility limitations, mission capability.

Test Article Description. Acceptance testing will be performed on all flight and spares equipment; therefore, no specific Test Article is required.

Test Description. Through planning and control of Supplier or Subcontractor acceptance test activities, functional receiving tests of Supplier or Subcontractor items may be limited to those which are critical, by virtue of the subsystem involved or due to either limited or lack of access following installation.

Principal Acceptance tests are essentially the same, for Spacecraft level testing, as those specified for Qualification testing, except that EMI/RFI and Shock test are eliminated from the test sequence. An Acceptance Test flow diagram is given in Figure 18.

Flight spacecraft acceptance tests, in addition to functional verification, include exposure to selected environmental conditions which are neither as severe or as extensive as those experienced during qualification testing. With the exception of Science payload instruments, all spacecraft subsystems

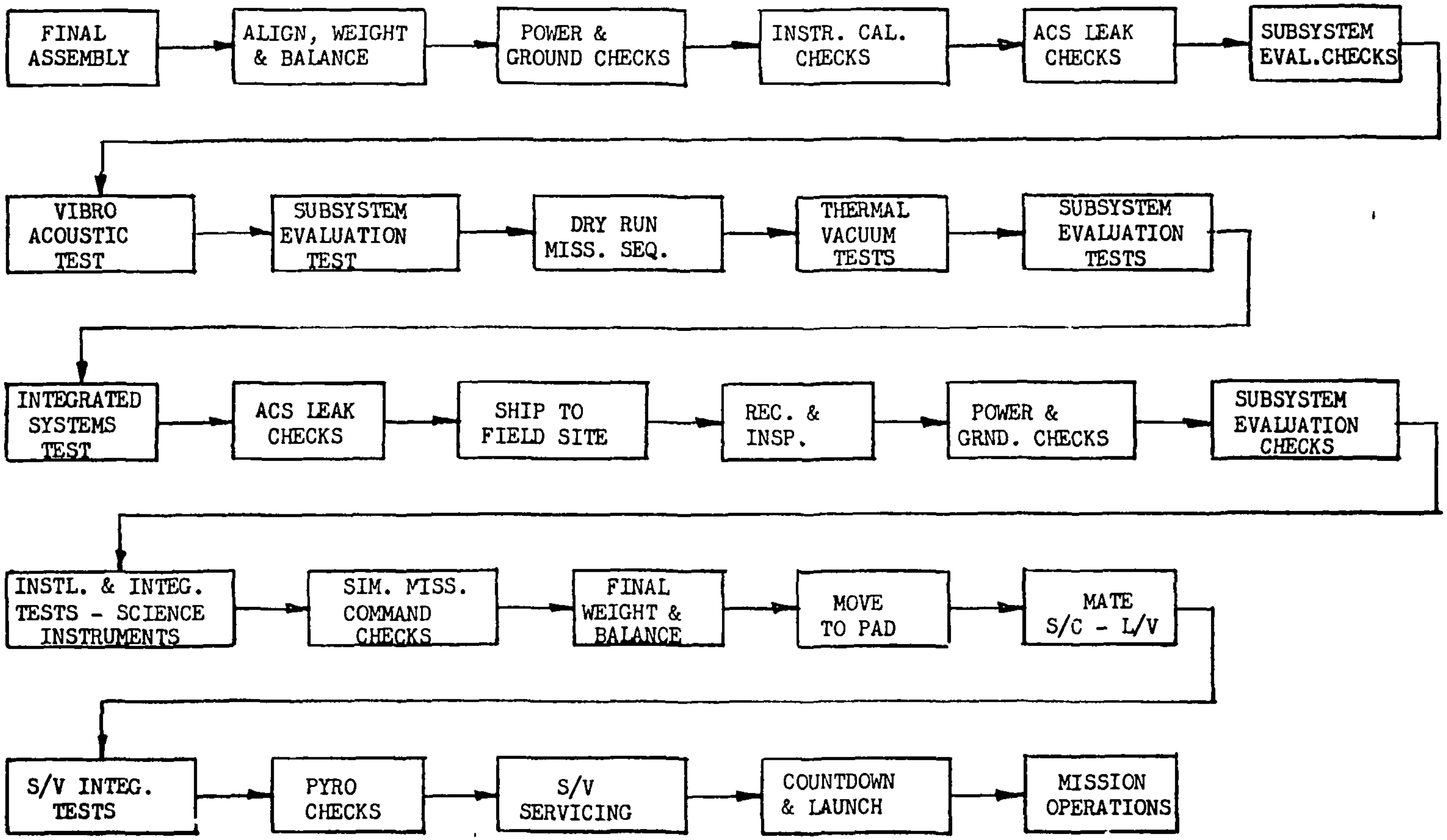

Figure 18. Flight Spacecraft Acceptance Flow Diagram

will be delivered to the Spacecraft Contractor for installation and Acceptance testing. Following installation and functional checkout of each subsystem, including antenna deployment checks, a combined subsystems evaluation test will be conducted to verify satisfactory operation. Test procedures will be followed which will simulate specific mission phases.

Application of vibration and acoustic loads during subsystems operation will verify the integrity of the subsystems installation and spacecraft assembly. The next major tests will be accomplished by subjecting the spacecraft to a series of functional tests in a thermal-vacuum chamber while simulating the environments of vacuum, solar flux, high and low temperatures. During this period, the spacecraft subsystems will be operated and performance monitored through test umbilicals connected to the Ground Support Equipment.

After successful completion of thermal-vacuum testing, integrated subsystems evaluation and Attitude Control System leak checks will be performed. Final pre-ship operations will include a complete assessment of spacecraft and support equipment configuration, and results of the acceptance tests, and spacecraft and support equipment packaging for delivery to the launch site.

Launch-Site Operations. The final phase of flight spacecraft operations will be accomplished at Kennedy Space Center (KSC). In addition to Receiving Inspection, the spacecraft Science Payload instruments will be installed and subsystems checkout performed, followed by a final weight and balance. Final checkout, prior to Launch Vehicle integration, will include an abbreviated combined systems test to verify the sequence and function of antennas and solar panel pyrotechnics, and Deep Space Network commands. Pyrotechnic simulators will be used to confirm proper voltage and current levels, and to monitor the firing circuits to assure absence of "sneak" circuits.

Following final flight readiness tests, the spacecraft will be moved to the launch pad and mated to the Launch Vehicle Centaur stage. Final spacecraft-Launch Vehicle integration tests will be conducted, followed by propellant servicing, closeout, countdown and launch. Table 3 shows a sample Test Matrix for Development, Qualification, and Acceptance tests.

Necessary Equipment and Facilities (Table 2). The supplier or Subcontractor of materials, components and subsystems will provide the equipment and facilities necessary for Acceptance testing to the subsystem level.

Table 3. Sample Test Matrix

Item	Test Item			Performance						Development							Qualification													Acceptance						Remarks
	Unit	Subsystem	System	Inspection	Performance	Mass Prop	Mech Align	Mech, & Elec Comp	Leak	Thermal	EMI/RFI	Static Loads	Modal Vibration	Vibration	Acoustics	Shock	EMI/RFI	Temp (Hdlg & Stor)	Temp (Alt)	Humidity	Explosive Atm	Acceleration	Space Simulation	Acoustics	Shock	Cont, Hi-Pot, Res	Vibration	Thermal Vac	Static Loads	Temp (Alt)	Space Env Sim	Vibration	Acoustics	Cont, Hi-Pot Res	Thermal Vac	
SEP-ABP System																																				
Structural Static Article			X	X		X	X					X																	X							
Development Test Spacecraft			X	X	X	X	X	X	X	X	X		X	X	X	X																				
Qualification Test Spacecraft			X	X	X	X	X	X	X								X							X	X	X	X	X								
Test firing at subcontractor			X	X	X	X	X	X	X																							X	X	X	X	
Subsystems																																				
Structure		X		X		X	X	X																												
Telecommunication and Data Processing		X		X	X	X	X	X		X	X						X	X	X	X								X		X					X	
Central Computing and Sequencing		X		X	X	X																														
Guidance, Navigation and Control		X		X	X	X	X	X	X	X					X													X				X			X	
Spacecraft Power and Cabling		X		X	X	X											X			X	X							X							X	Without batteries in thermal vacuum
Thermal Control		X		X	X	X		X		X																										
Electric Propulsion		X		X	X	X	X	X	X	X	X			X			X											X							X	Test firing at subcontractor
Solar Panels		X		X	X	X	X	X						X													X					X			X	Less solar cells for development spacecraft tests
Science		X		X	X	X	X	X									X																			GFE - Available for ON-OFF functional test
Pyrotechnics		X		X	X	X	X	X		X										X	X						X									Explosives simulated
Independently Mounted Actuators		X		X	X	X	X	X		X				X													X	X				X			X	
Ground Support Equipment		X		X	X			X	X																											

The Spacecraft Contractor will utilize previously accepted Ground Support Equipment and Spacecraft subsystems in performing the flight Spacecraft Acceptance Tests.

In addition to those facilities required for Development testing, facilities are required at KSC for prelaunch assembly and checkout, and launch

4.4.3.3 Task Summary

Tasks necessary for implementation of this plan are summarized below. Work Breakdown Structure numbers are utilized within the applicable Program Phase (Figure 3).

Phase B

WBS 4.5	Provide Test inputs to Preliminary Reliability and System Safety Requirements Plan
WBS 4.6	Provide preliminary Program Test Plan, test schedules, and cost estimates Provide updated Program Test Plan and detailed cost estimates
WBS 4.10	Coordinate Preliminary Program Test Plan with requirements of Engineering Development Plan
WBS 5.0	Provide Test requirements inputs for preliminary facilities definition
WBS 5.3	Coordinate preliminary Test requirements with preliminary Facilities Plan
WBS 6.0	Provide Test inputs for preliminary GSE definition
WBS 6.1	Coordinate preliminary requirements of GSE Plan with those of the Preliminary Program Test Plan
WBS 7.2	Provide Test inputs for Special Test Equipment preliminary requirements definition
WBS 8.0	Provide Test inputs for Logistics support

WBS 8.3 Provide Test requirements for spares to Logistics

WBS 8.4 Coordinate preliminary Logistics Support Plan requirements with Preliminary Test Plan requirements

Phase C

WBS 4.0 Provide Test support for PDR documentation and participation

WBS 4.5, 4.6, 4.10, 5.0, 5.3, 6.0, 6.1, 7.2, 8.0, 8.3, and 8.4 as for Phase B

Phase D

WBS 1.0 Accomplish Static Structural and Development Test Spacecraft tests

WBS 1.12 Prepare Test and Checkout Procedures for Static Structural and Development Test Spacecraft tests

WBS 2.0 Accomplish Qualification Spacecraft tests

WBS 2.12 Prepare Test and Checkout Procedures for Qualification Spacecraft tests, and Flight Spacecraft Acceptance tests

WBS 3.1 Provide Test support documentation and participation for CDR, FACI, and FRR
Spacecraft Acceptance tests

WBS 4.6 Release Program Test Plan; provide Test support for CDR documentation and participation, and for FACI and FRR

WBS 5.0 Provide Test support for Test Facility checkout

WBS 6.0 Accomplish GSE pre-spacecraft checkout

WBS 9.0 Provide Test Operations support for Prelaunch and Launch Operations

4.4.4 IMPLEMENTATION AND MANAGEMENT

4.4.4.1 Organization

A simplified organization chart showing a typical Test organization required to implement this plan is shown on Figure 19.

4.4.4.2 Schedules and Milestones

Preliminary Test Task Summary Schedule

A summary bar-type schedule, with major milestones, is shown in Figure 20.

Preliminary Integrated Program Test Schedule

A Preliminary Integrated Program Test Schedule showing gross time spans for Structural Static Test Article, Development Test Spacecraft, Qualification Test Spacecraft, and Flight Spacecraft is shown in Figure 21.

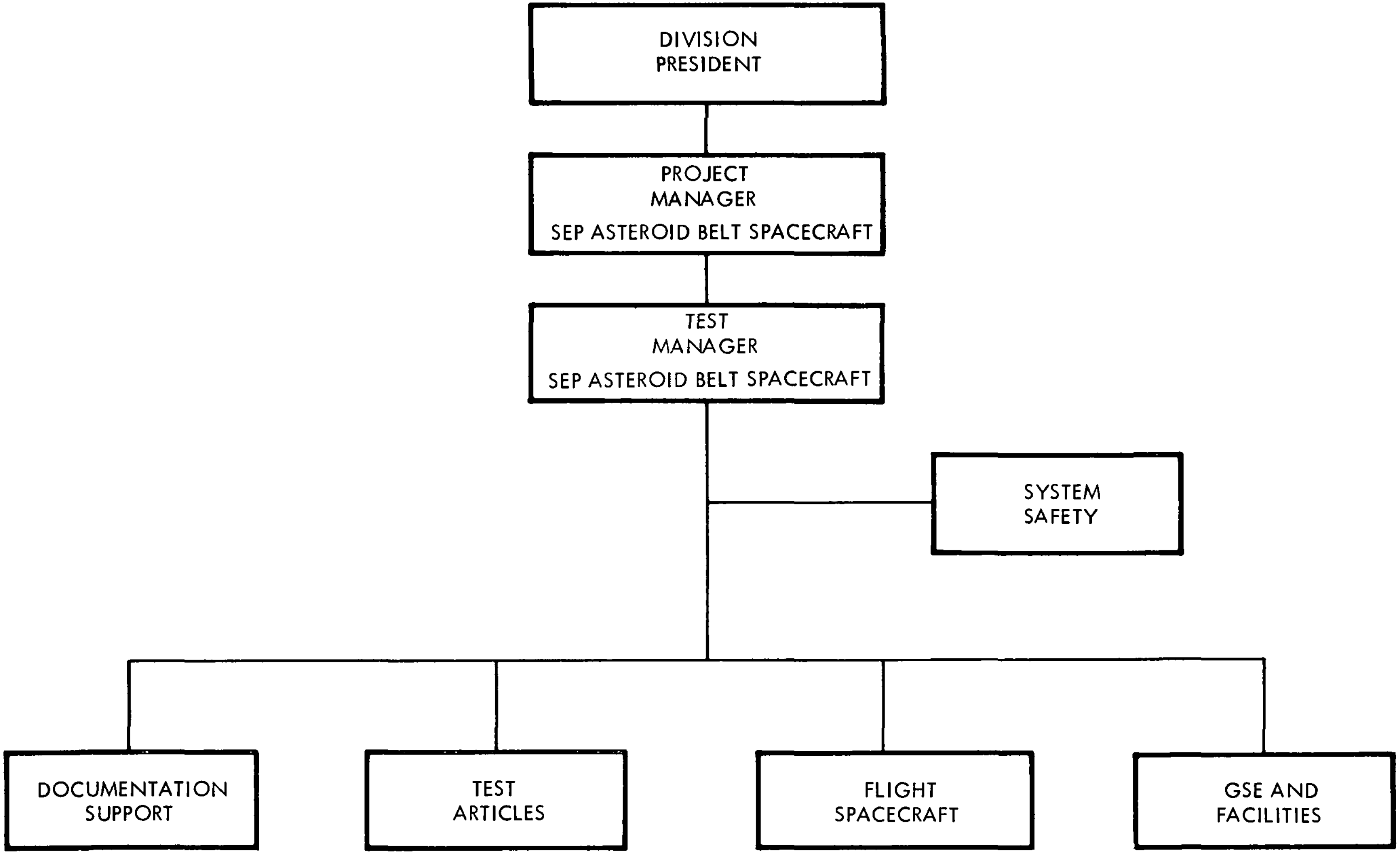

Figure 19. Test Organization Chart

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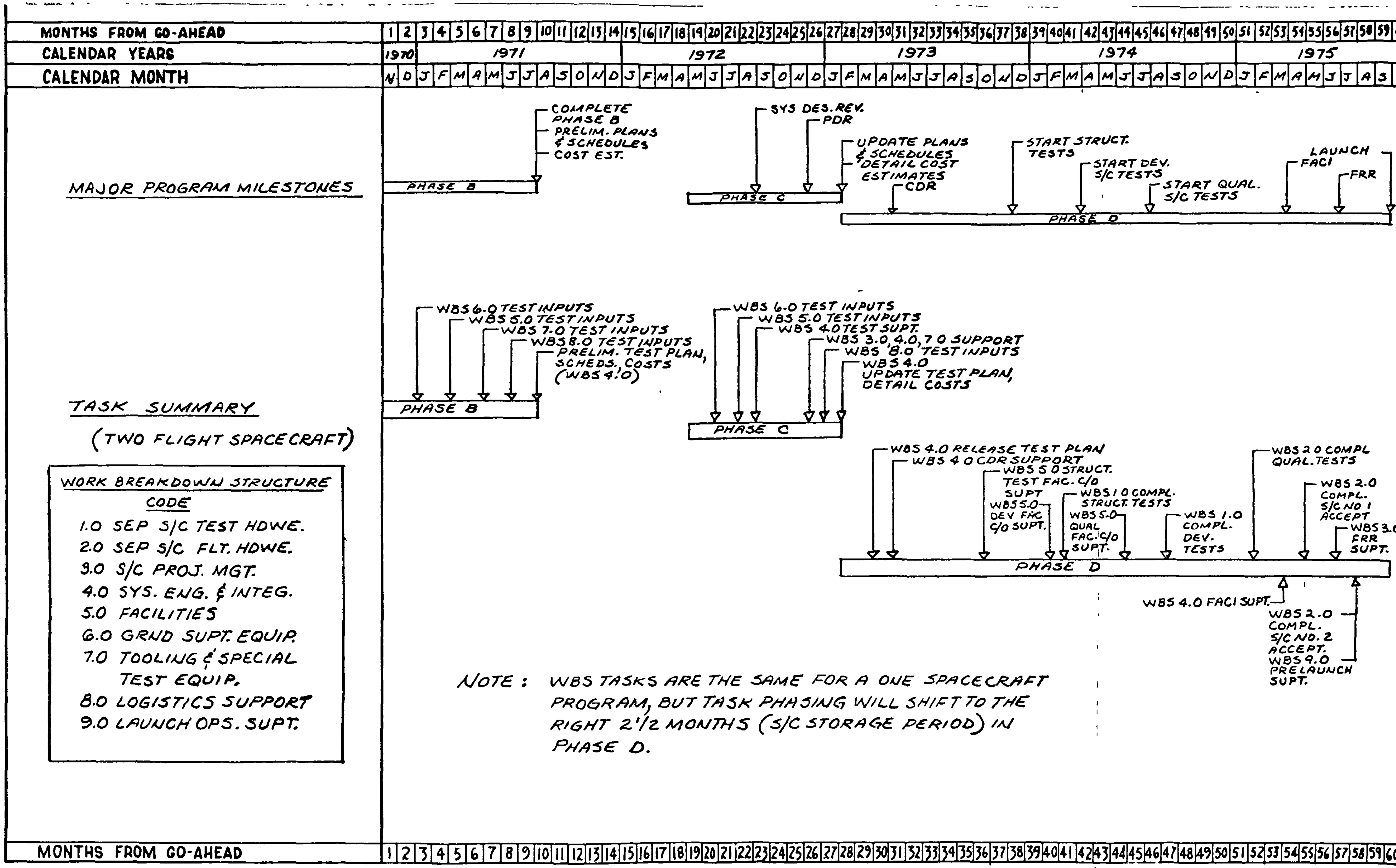

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Figure 20. Preliminary Test Task Summary Schedule

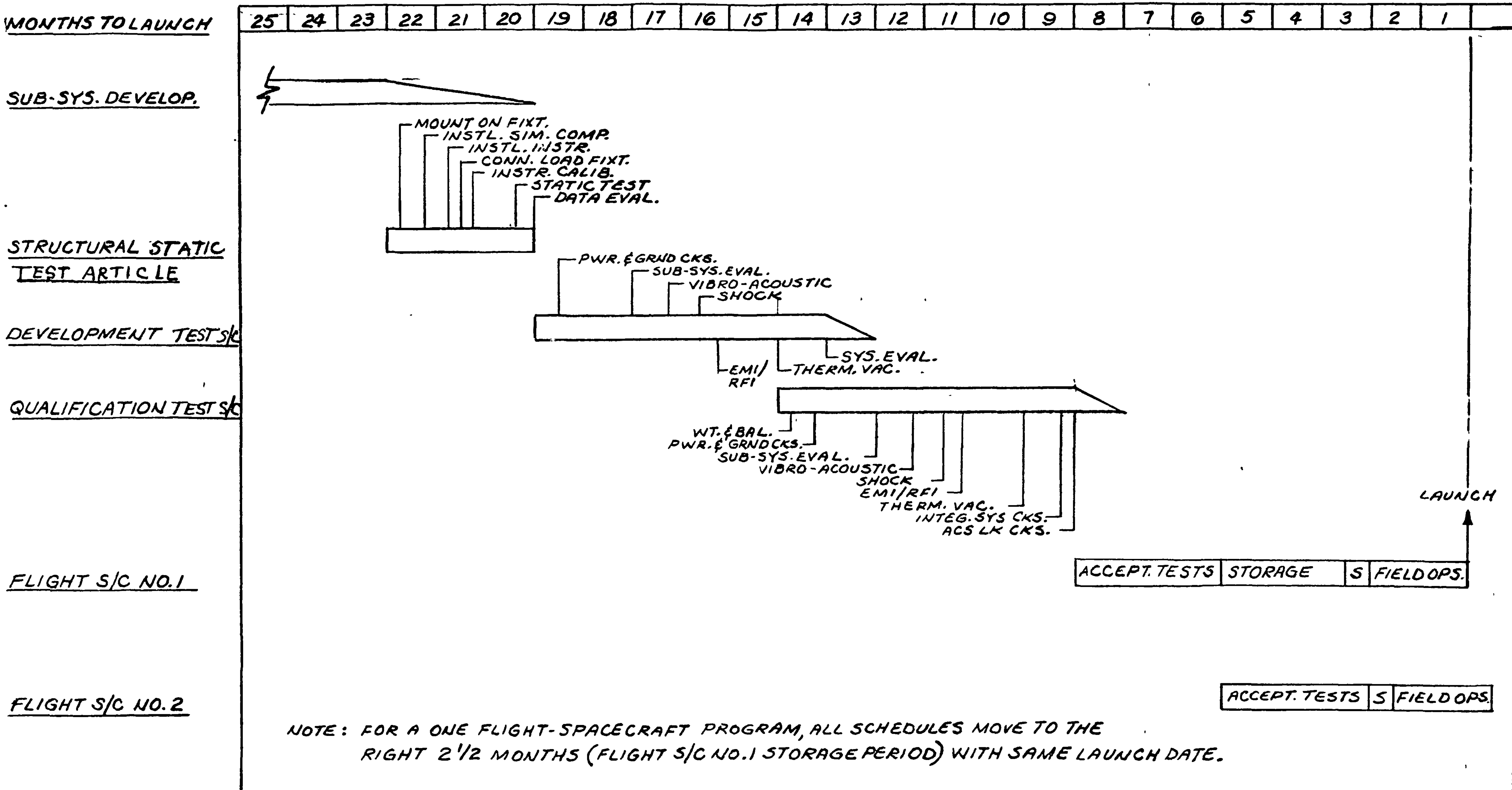

Figure 21. Preliminary Integrated Program Test Schedule

4.5 GROUND SUPPORT EQUIPMENT PLAN

4.5.1 PURPOSE

This plan defines the effort required to produce equipment and associated software to support the Solar Electric Propulsion Asteroid Belt Mission spacecraft through all phases of test and ground operations.

4.5.2 SCOPE

This plan describes the approach for establishing functional and design requirements for Ground Support Equipment (GSE). Criteria for qualification and acceptance of hardware and a plan for integration into a checkout system are covered. Philosophy for selection of equipment and components is described.

4.5.3 TASK DESCRIPTIONS

4.5.3.1 Requirements

The Solar Electric Propulsion (SEP) spacecraft will require support equipment and the accompanying software during the development test, qualification test, and operational phases. The requirements fall into the following major categories:

Handling equipment to position and support the spacecraft and provide access during the tests.

Gaseous nitrogen servicing equipment to check the onboard attitude control system and load GN_2 in preparation for tests or launch.

Mercury propellant servicing equipment to check, load, and pressurize the electric propulsion reservoir and manifolding system.

Equipment to supply electrical power to the on-board power system during ground operations.

Equipment to check the functional integrity of the control systems.

Equipment to provide a two-directional data link to interface with the communication and data system. The data are to be coded in a form compatible with the on-board systems.

Equipment to check and calibrate the sun sensors and star tracker subsystems.

Special instrumentation for the development test and the qualification test programs.

Software to support the various program phases, which will include computer programs, GSE verification test procedures, and calibration data for test instrumentation.

4.5.3.2 Rationale for Selecting Tasks and Defining Scope

The selection and scope of tasks are based on the GSE end items needed to support the requirements of the spacecraft subsystems during tests and operations. These GSE items are included in the Hardware Utilization List (Table 6). Maximum use will be made of existing GSE which will satisfy the needs of the spacecraft. Emphasis is placed on the systems approach, wherein overall system functions, including spacecraft and GSE, are integrated and defined in a functional schematic. The GSE is to be developed concurrently with the spacecraft subsystems. This approach will simplify integration of the GSE and facilitate GSE design by establishing firm functional requirements in a timely manner.

Maximum use shall be made of presently developed and available equipment. A notable example is equipment developed to support the 1969 Mariner Mars probe telecommunication system. The SEP Asteroid Belt Mission spacecraft will use a similar communication system. Therefore, the same type of GSE will satisfy the support requirements.

GSE for the electric propulsion system will be furnished by the propulsion subcontractor. The prime contractor shall coordinate requirements and integrate the GSE into the total ground support system.

Quantities of GSE end items are based on the assumption that schedules will permit the development test and qualification test GSE to be used later for support of a flight spacecraft.

4.5.3.3 Task Summary

Furnishing GSE to support the SEP spacecraft will require effort defined by the following tasks:

Coordinate with the spacecraft subsystem designers and establish GSE functional requirements. Document the requirements by means of functional integrated schematics.

Establish design requirements in accordance with intended usage. Include EMI control plan, environment definition, and reliability requirements.

Perform research to determine whether need can be filled by existing equipment or whether the equipment will be built in-house or purchased.

For equipment to be built in-house, write an end-item specification (EIS), prepare production drawings, and write an acceptance test specification.

For each purchased item, write a procurement specification and conduct the procurement activity.

Document the integration and management techniques whereby the individual GSE models will become a unified operationally effective ground system.

4.5.4 IMPLEMENTATION AND MANAGEMENT

4.5.4.1 Organization

To integrate the GSE effectively into a ground system responsive to development, qualification, and test requirements, the organization will be as depicted in Figure 22.

4.5.4.2 Schedules and Milestones

Task Summary and Major Milestones

A schedule for development and utilization of the GSE end items is shown in Figure 23. The schedule is based on the Two-Flight Spacecraft Program. Equipment need dates would be approximately two months later for the One-Flight Spacecraft Program.

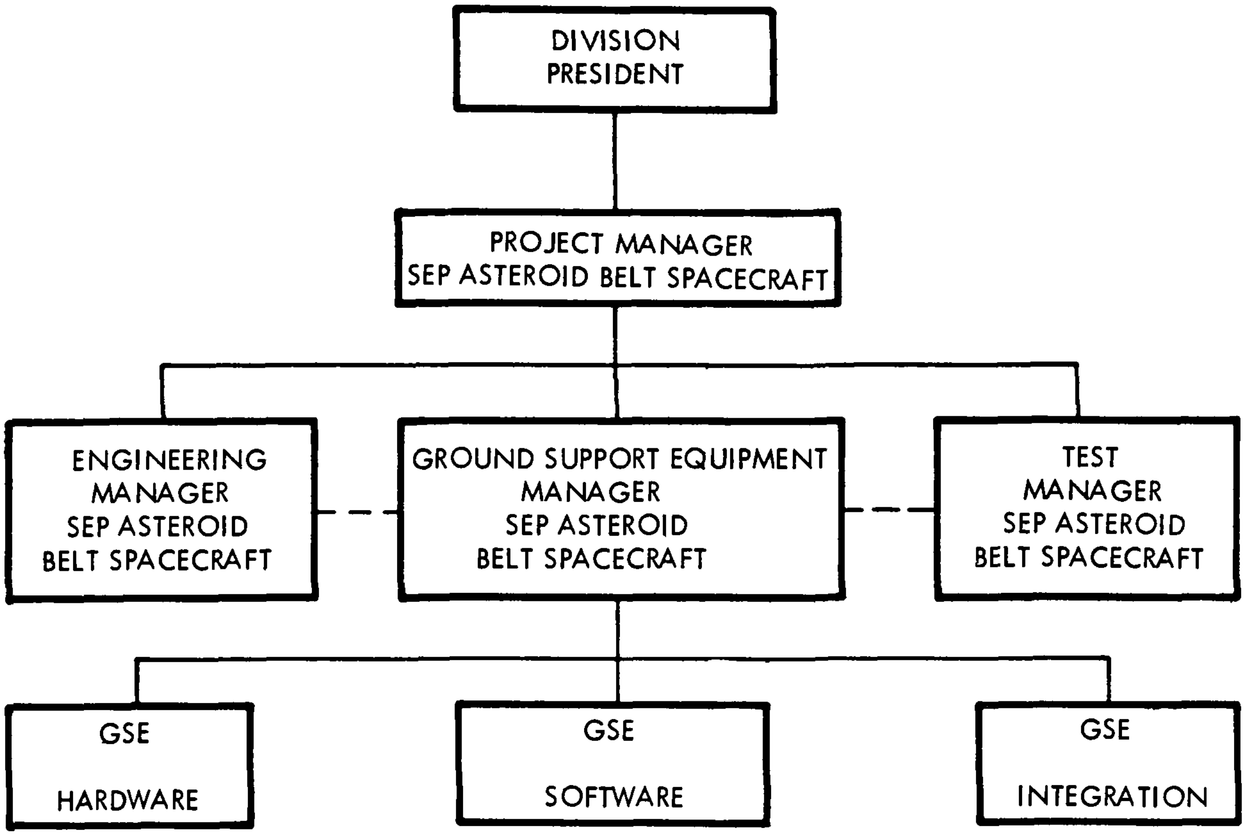

Figure 22. Ground Support Equipment Organization Chart

Formal Reviews

Two formal reviews shall be conducted during development of the GSE. The first will be the Preliminary Design Review (PDR). This shall be held prior to the start of the production drawings or release of the procurement specifications. The documents presented shall include the GSE Plan, integrated functional schematics, preliminary end item specifications and procurement specifications, and GSE design criteria. The second review will be the Critical Design Review (CDR), which shall consist of a pre-release production drawings, final procurement specifications, and preliminary test procedures.

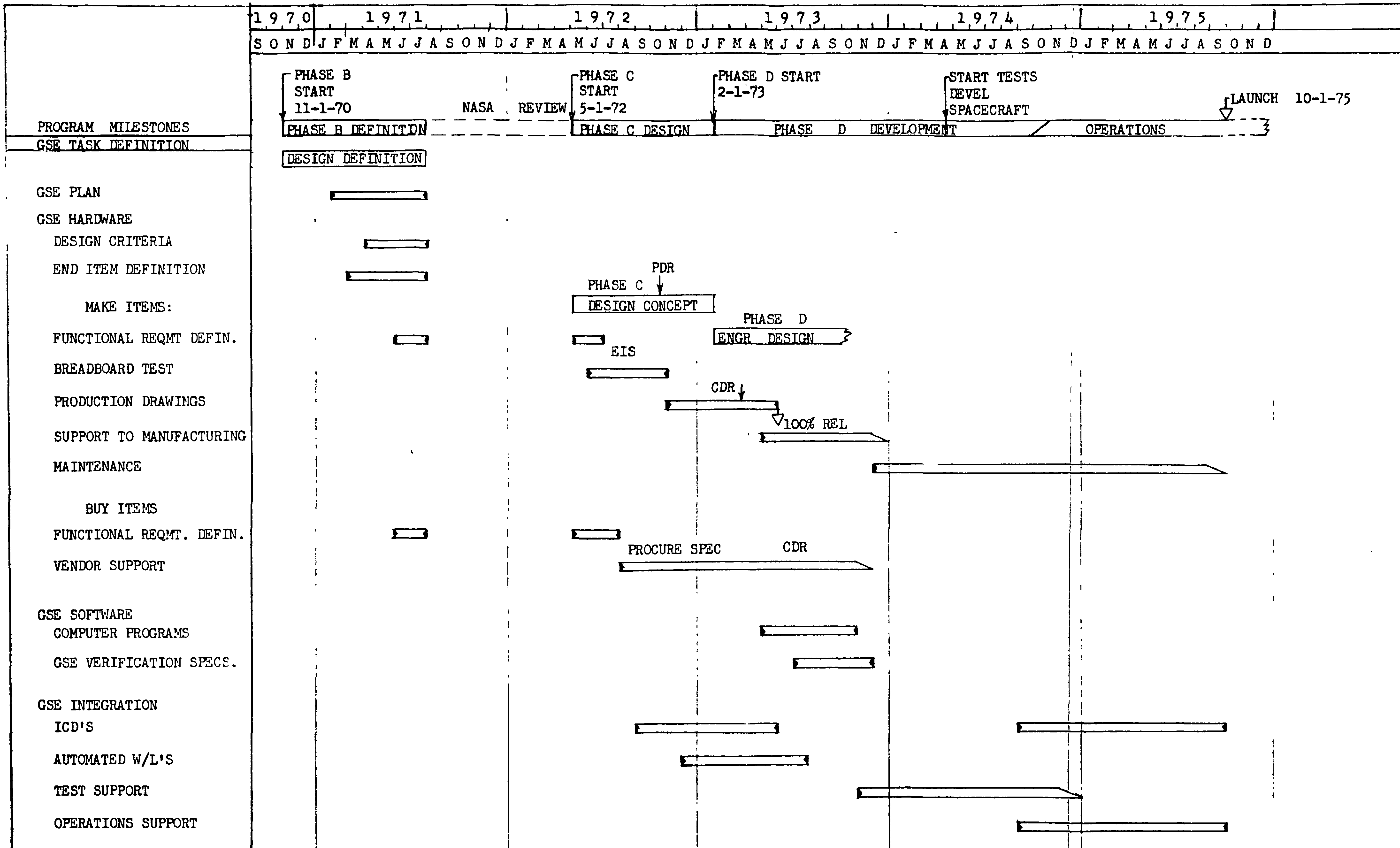

Figure 23. Preliminary Ground Support Equipment Development Schedule

4.6 FACILITIES PLAN

4.6.1 PURPOSE

The purpose of the Facilities Plan is to identify plant and related equipment requirements and to describe the means for providing Facilities and Industrial Engineering support to the design, fabrication, and test of the spacecraft for the Solar Electric Propulsion Asteroid Belt Mission Program.

4.6.2 SCOPE

The scope of activity is limited to facilities and related equipment required for use by the spacecraft prime contractor and facilities, equipment, and industrial engineering required for manufacture, test, engineering, and supporting functions.

This section does not cover launch facility requirements or facilities required by the Electric Propulsion System subcontractor or other subcontractors

4.6.3 TASK DESCRIPTIONS

4.6.3.1 Requirements

Facilities and plant equipment will be required for the design, fabrication, and testing of major items of hardware determined during the current contract for achieving the program objectives. The major hardware items will consist of one soft mockup, one structural static test article, one development test spacecraft, one qualification test spacecraft, and one or two flight spacecraft

The Manufacturing and Test Departments will require Industrial Engineering work standards.

Material handling and parts protection equipment will be required to move, protect, and store the spacecraft and parts during fabrication, testing, and shipping. Material handling and parts protection activity must begin early in the program in order that equipment will be available for fabrication and assembly of all test articles made with hard tooling.

Milestones on the preliminary Facilities Schedule identify the phasing of equipment necessary for program support and optimization of fabrication and storage. All jigs, dollies, fixtures, and protective devices required for fabrication and subassembly of parts and final assembly and checkout must be provided.

Test requirements must be evaluated, and long procurement lead time items must be identified to permit activation of test and checkout facilities within the schedule period.

The test and checkout facilities task must provide for the design, construction, and surveillance of services and utilities required to support the final acceptance test systems. Criteria development and interfaces with organizations involved must be provided by the facilities technical support task. This function will provide utilities such as electrical power and high-pressure gas and facility modifications to interface with the Solar Electric Propulsion checkout system.

4.6.3.2 Rationale for Selecting Tasks and Defining Scope

The selection of tasks and determination of their scope were based on the assumption that existing NR Facilities and equipment, or equivalent, would be used as a starting point in meeting requirements of this program.

4.6.3.3 Task Summary

The Facilities and Industrial Engineering (F&IE) activities are summarized as follows:

1. Update the Facilities Plan during Phases B and C
2. Provide support for Manufacturing and Test Operations
    a. Facilities for fabrication of a soft mockup.
    b. Material Handling and Parts Protection Equipment Plan.
    c. Support for Manufacturing - Phase D.
    d. Support for Test Operations - Phase D.

4.6.3.4 Detailed Task Descriptions

Facilities Plan

The Facilities Plan will provide direction for F&IE's participation in Phases B, C, and D effort and will assign responsibilities to ensure satisfactory performance. It will define existing contractor and Government facilities utilization and the additional facility requirements generated by this program. Analyses and studies will be performed, and interfaces with other functional groups will be established to ensure optimum coverage of all facility needs.

Facilities Plan - Phase B.

Complete preliminary studies and analysis to develop facilities requirements for Manufacturing and Test Operation to be conducted during Phases C and D.

Determine contractor and Government facility requirements by tradeoff analysis and utilization studies.

Plan for special test equipment requirements.

Plan for the utilization of machinery and equipment and other support requirements.

Identify long-lead-time facility items.

Analyze and plan for facilities funding.

Provide preliminary planning for material handling and parts protection equipment.

Facilities Plan - Phase C.

Continue Facilities and Industrial Engineering studies for development of requirements to support Manufacturing and Test Operations in Phase D.

Complete final design for material handling and parts protection equipment.

Make the final plan for utilization of special test equipment

Facilities Support for Manufacturing and Test Operations

This task will provide for the analysis of production requirements and making pre-production rearrangements Industrial Engineering will analyze Engineering's plans and specifications to establish the optimum production work sequences and determine the work standards to be used by Planning and Scheduling. A mechanized planning and control system will be utilized to provide information for planning, controlling, and reporting the status of work. Industrial Engineering will provide the analysis and methods for improvement of work plans (Appendix A). Material Handling will provide all necessary equipment to hold, move, and protect the parts and spacecraft through all manufacturing and test operations.

Facilities for Fabrication of Soft Mockup

Provide facilities for fabrication of a soft mockup during Phase C.

Material Handling and Parts Protection Equipment Plan. Since it is desired to use the same material handling equipment for test articles and flight spacecraft, it will be necessary, early in the program, to establish an interface with Engineering to obtain needed design criteria. Detailed drawings and specifications for fabrication or purchase of equipment will be accomplished in the Facilities Design group. Minimum requirements for material handling equipment and parts protection devices are shown in Table 4. The Material Handling and Parts Protection Plan (Appendix B) should be updated during Phase C.

Support for Manufacturing - Phase D.

Make pre-production rearrangements.

Provide and maintain work standards and analytical industrial engineering support (Appendix A).

Provide material handling and parts protection equipment.

Provide program technical support.

Support for Test Operations - Phase D.

Provide and maintain work standards and analytical industrial engineering support (Appendix A).

Provide material handling and parts protection equipment (Appendix B).

Activate and maintain the Test and Checkout Facility.

Provide program technical support

Program change control.

Special Test Equipment Evaluation.

Table 4. Material Handling Equipment for Parts Protection

Item Description
Rack, Frame, Parts Prior to Assembly
Dolly, Trunnion for Assembly and Transport
Sling, Propulsion System Module
Sling, Solar Cell Array
Sling, Subsystem Module
Sling, Science Module
Sling, Structural Assembly Turnover
Carriage, Assembly for Vacuum Chamber
Dolly, Structural Assembly Transport
Sling, Assembly
Cover, Thermo-Vacuum Transport
Workstand, Assembly and Installation

Activation and Maintenance of Test and Checkout Facility

This task will utilize data on the operational needs and specifications of the selected checkout system to develop design criteria for installation and operation of the system in NR Space Division, Building 290, or equivalent. The Facilities Design group will convert the criteria into construction drawings and specifications for required modifications and utilities.

The requirements for Thermo-Vacuum facilities, which will be capable of supporting testing requirements of the Solar Electric Propulsion Spacecraft, are as follows:

1. Sufficient size for a 20-foot-long vehicle.

2. A pumping system capable of maintaining 10^{-5} torr during test.

3. An operating temperature of -310 F. to +125 F.

4. A solar simulation capability with a flux density variable from 11.4 watts per meter^2 to 140 watts per meter^2.

A number of Government and privately owned facilities can support this requirement. The selection could be made during the contract for Phases C and D. A partial survey conducted by NR during this study indicates a number of potential facilities. Table 5 lists these facilities and their general characteristics.

4.6.4 IMPLEMENTATION AND MANAGEMENT

4.6.4.1 Organization

A Manufacturing and Facilities Manager shall be appointed at the beginning of Phase B. He shall direct all activities through a project-type organization. He shall report directly to the Spacecraft Project Manager. Figure 24 illustrates the organizational structure and reporting channels.

4.6.4.2 Schedule and Major Milestones

The SEP Spacecraft Facilities Schedule provides the time phasing and major milestones for the principal task areas of F&IE's participation, listed in the task summary (4.6.3 3).

The final Facilities Plan will be completed by the end of Phase C and will provide direction and guidelines for all F&IE work, including burden activity such as minor rearrangements necessitated by Engineering, Test, or Manufacturing requirements of the program.

Facilities technical support will be active during Phases B, C and D. This will provide an interface with all program areas and include participation in program change control, special test equipment evaluation, and procurement support. Liaison with program activities and anticipated support functions are summarized below.

Date	Activity
01-70	Establish Initial Office Area
09-70	Provide Administration and Engineering Area (for Phase B)

Table 5. Potential Thermo-Vacuum Facilities for Testing SEP Spacecraft

Facility	Size	Pressure (Torr)	Temperature (°F)	Solar Simulation
GE - King of Prussia, Pennsylvania	32-ft dia x 54 ft high, vertical	10^{-8}	-279 5 F	17-ft-dia spot, 120 - 140 watt sq ft
RCA - Princeton, New Jersey	26-ft dia x 20 ft high, vertical	$5\ 79 \times 10^{-9}$	-300 F to +250 F	Planned, never installed
JPL - Pasadena, California	25-ft dia x 42 ft high, vertical	1×10^{-6}	-320 F to +125 F	15-ft-dia spot
Bendix - Ann Arbor, Michigan	20-ft dia x 27 ft long, horizontal	5×10^{-8}	-310 F	Carbon arc 6-ft dia spot
NASA - Houston, Texas (Chamber B)	25-ft dia x 30 ft high, vertical	10^{-6}	-310 F	Spot carbon arc 5 ft 6 in
NASA, Houston, Texas (Chamber A)	65-ft dia x 125 ft high, vertical	10^{-5}	-310 F	13 ft dia and 13-ft x 33-ft side carbon arc
USAF, Arnold AFB, Tennessee	35-ft dia x 65 ft high, vertical	10^{-6}	-310 F	12-ft x 15-ft area
TRW - El Segundo, California	30-ft-dia sphere, 19-ft door opening	3×10^{-9}	-310 F to +275 F	Carbon arc 10-ft x 10-ft area

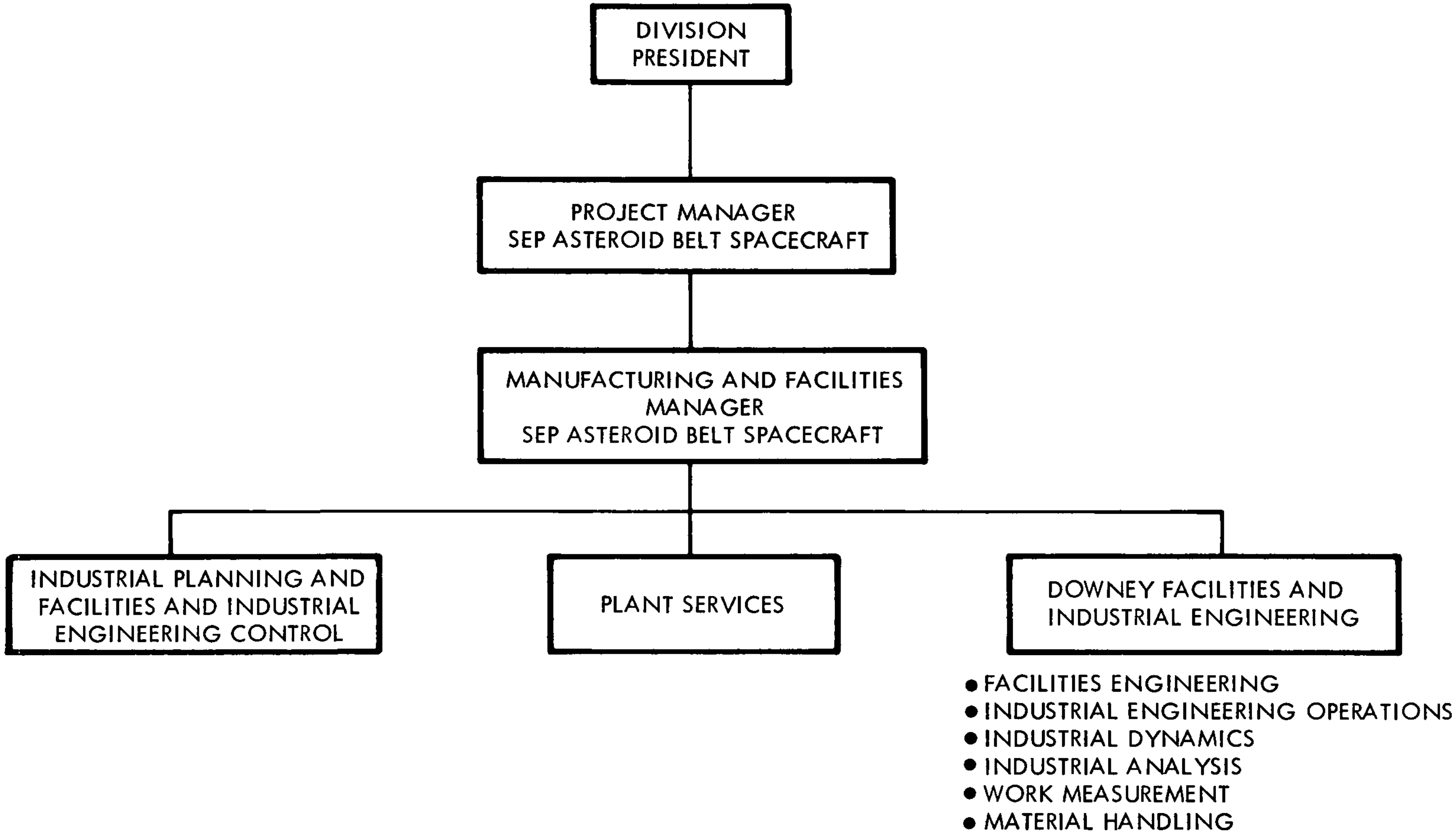

Figure 24. Facilities Organization Chart

Date	Activity
03-72	Support Engineering Design Criteria Laboratory Programs
04-72	Support Soft Mockup Fabrication
01-73	Support Test Articles Manufacture
09-73	Support Structural Test
01-74	Support Dynamic Test
07-74	Support Flight Spacecraft Fabrication
09-74	Support Assembly and Test
01-73	Support Quality, Test, and Failure Analysis Programs

Figure 25, The Preliminary Facilities Schedule, relates the Facilities and Industrial Engineering Work Breakdown Structure tasks to the program phases, thereby depicting the major milestone support requirements by date. This schedule will be updated during each of the phases of the program.

4.6.4.3 Implementation

Cost Avoidance and Interface With Other Plans

This task will integrate F&IE with other functional groups active in program performance. Points of contact will be established, and liaison will be maintained to coordinate activity to eliminate schedule constraints and interface problems. Rearrangement of personnel and equipment to meet specific program needs will be identified and implemented under this task. Activity will include coverage of the administration and engineering offices, production facilities, and laboratory and test facilities. The effort will include participation in program change control, cost and schedule control, technical support, and pre-acquisition evaluation and installation of special test equipment and Government furnished equipment.

Facility and equipment requirements established by Manufacturing and by Test Operations will be analyzed to provide optimum results to the program. Industrial Engineering analysis will maximize the use of presently available facilities and equipment in order to minimize program costs.

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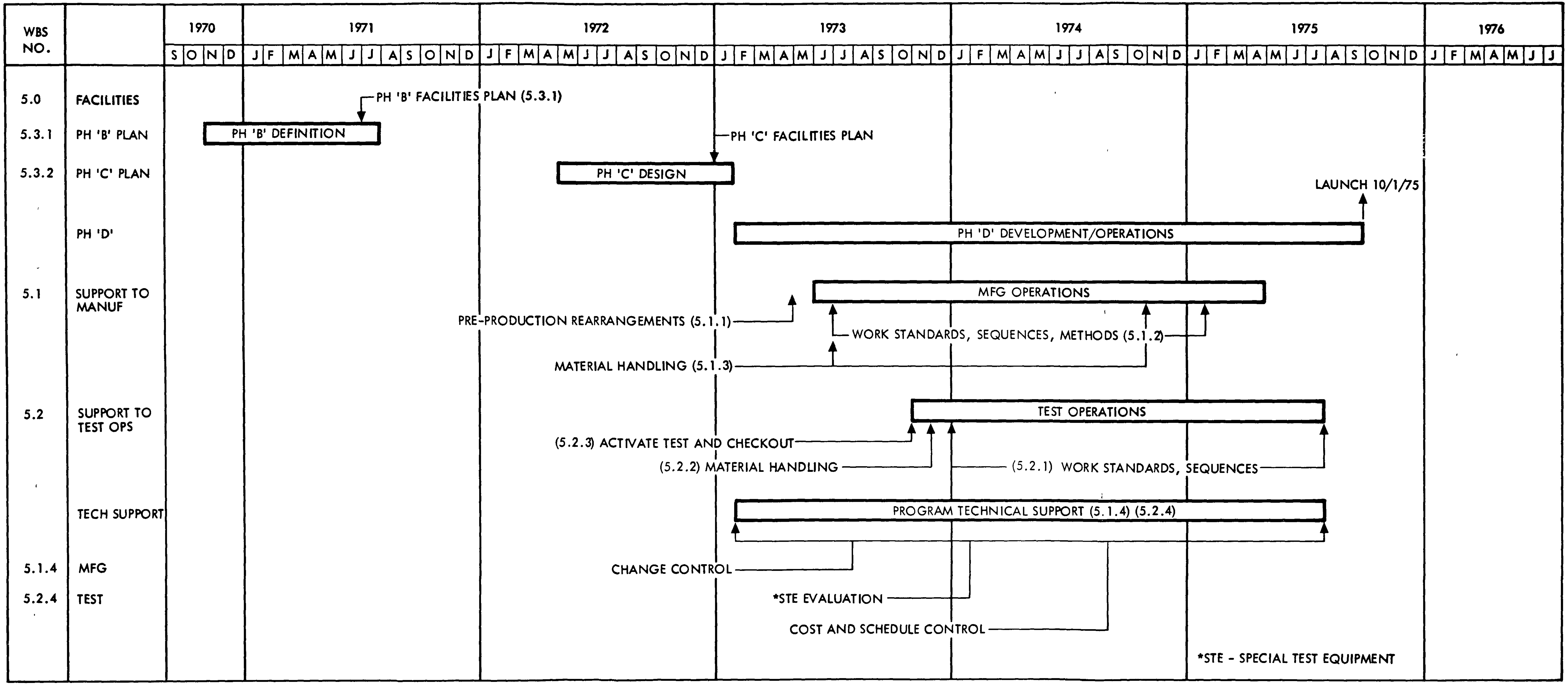

Figure 25. Preliminary Facilities Schedule

Location of Facilities

Figure 26 (the NR Downey Complex) and Figure 27 (the NR Los Angeles Division Complex) indicate the type and location of major support facilities that would be required by a prime contractor for engineering, development, production, and test of the spacecraft. The location of a large thermo-vacuum facility capable of solar simulation will be determined incident to Phases C and D of the program, as discussed in paragraph 4.6 3 4.

Detail of Available Facilities

See Appendix C for a description of the following facilities, which can accommodate the major prime contractor requirements of the program.

Administration and Engineering Offices

Production Facilities

Model Shop

Laboratory and Test Facilities

Computing Services

Radiation Laboratory

Electrical-Electronics Laboratory

Dynamic Simulation Testing

Thermal Simulation

Vacuum Testing

Structural Testing

Pressure Testing

EMI/RFI Testing

Acoustic Testing

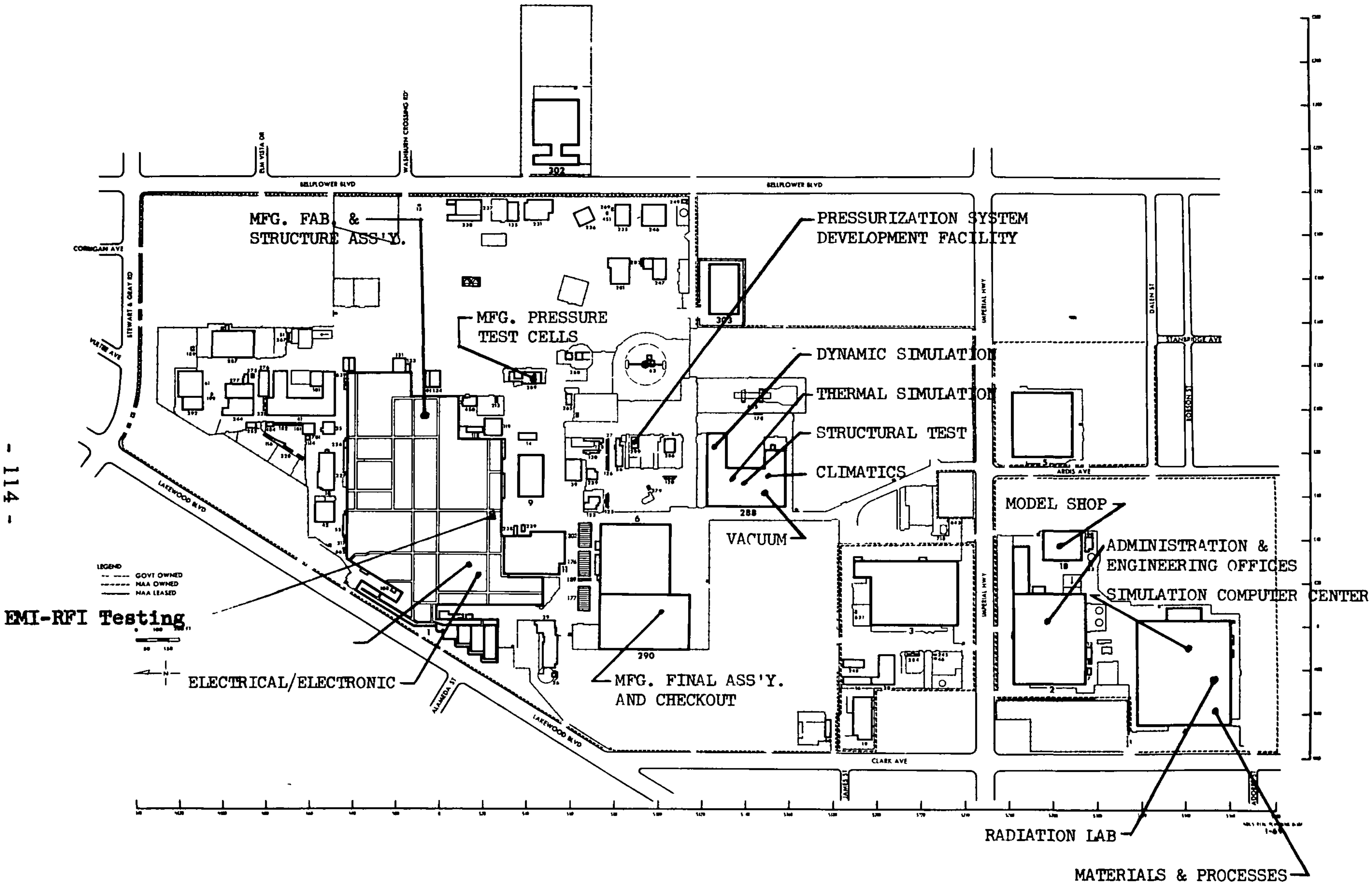

Figure 26. NR Space Division Downey Complex

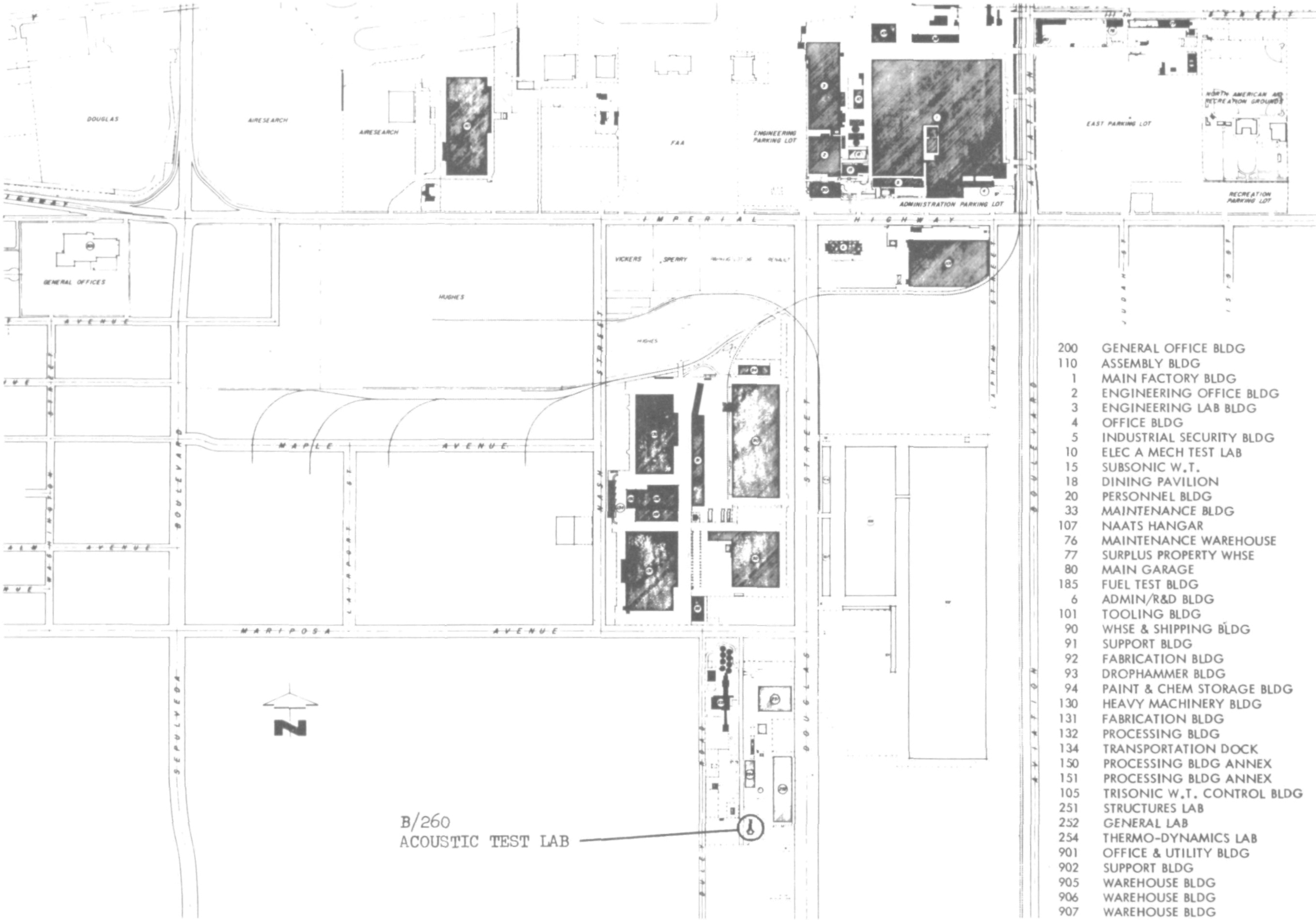

Figure 27. NR Los Angeles Division Site Plan

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5.0 HARDWARE UTILIZATION LIST

Table 6 is the preliminary hardware utilization list (HUL) for the Solar Electric Propulsion Asteroid Belt Mission Program. The HUL defines the major components, including spares, required for test articles (structural static test article, development test spacecraft and qualification test spacecraft), flight spacecraft (one- and two-flight spacecraft programs), and ground support equipment. The HUL also includes the requirement for a soft mockup. The HUL shows preliminary make-or-buy determinations, and items that would be Government-furnished equipment. The HUL contains essential information that was used in the preparation of the Program Development Schedule, subsidiary program plans, preliminary equipment specifications, and program cost estimates.

The HUL is based on the hardware tree/hardware portion of the work breakdown structure, a determination of the number and purpose of test articles/test spacecraft, and the hardware requirements for one- and two-flight spacecraft. A reasonable number of spares are included, based on past NR Space Division experience and the nature of this program.

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Table 6. Hardware Utilization List (Cont)

Item Description	M = Make B = Buy G = GFE	Development State: Existing: As Is	Development State: Existing: Modified	Development State: New	Test Hardware Requirements: Breadboard	Test Hardware Requirements: Structural Static Test Article	Test Hardware Requirements: Development Test Spacecraft	Test Hardware Requirements: Qualification Test Spacecraft	Test Hardware Requirements: Other Test Hardware	Test Hardware Requirements: Total	WBS Block No	Flight Hardware Requirements: 1 Flt SC: SC Requirements	Flight Hardware Requirements: 1 Flt SC: Spares	Flight Hardware Requirements: 1 Flt SC: Total	Flight Hardware Requirements: 2 Flt SC: SC Requirements	Flight Hardware Requirements: 2 Flt SC: Spares	Flight Hardware Requirements: 2 Flt SC: Total	WBS Block No	Total Requirements (Test and Flight): 1 Flight Spacecraft	Total Requirements (Test and Flight): 2 Flight Spacecraft
Spacecraft Power and Cabling											1 5							2 5		
Batteries	B		X				2	3		5		2	1	3	4	1	5		8	10
Power conditioning and control set*	B		X				1	1		2		1	1	2	2	1	3		4	5
Power distribution harness	M			X			1	1		2		1	1	2	2	1	3		4	5
Thermal Control											1 6							2 6		
Insulation	B	X					1	1		2		1		1	2		2		3	4
Surface coatings	B	X					1	1		2		1		1	2		2		3	4
Thermal isolators	B	X				100	100	100		300		100	30	130	200	60	260		430	560
Electric heaters	B	X					20	20		40		20	5	25	40	10	50		65	90
Bimetallic louver panel	B	X				1	1	4		5		4	1	5	8	1	9		10	14
Electric Propulsion System											1 7							2 7		
Thrusters	B			X			5	5		10		3	1	4	6	1	7		14	17
Translator and support tray	M			X			1	1		2		1		1	2		2		3	4
Power conditioners	B			X			3	4		7		2	1	3	4	1	5		10	12
Propellant reservoir and manifolding	B			X			2	2		4		1	1	2	2	1	3		6	7
Controls and switching network	B			X			1	1		2		1		2	2		2		3	4
Gimbal	B			X			3	3		6		3	1	4	6	1	7		10	13
Feed system	B			X			2	2		4		1	1	2	2	1	3		6	-
Solar Array/Capacitor Detector Assembly											1 8							2 8		
Roll-up arrays (flight)*	B				X			1		1		4		4	8		8		5	9
Roll-up arrays (test, less cells) (Includes capacitor detectors bonded to back of solar panels)	B				X			4		4									4	4
Science											1 9							2 9		
Faraday cup	G																			
He magnetometer	G																			
Geiger mueller counter	G																			
Cosmic ray spectrometer	G																			
Triaxial particle spectrometer	G																			
Sisyphus optical detector	G																			
Electro-static ballistic pendulum	G																			
Pyrotechnic Devices											1 10							2 10		
High-gain antenna pin puller	B		X				3	6		9		6	6	12	18		18		21	27
Low-gain antenna pin puller	[illegible]		X				3	6		9		6	6	12	18		18		21	27

*Preliminary equipment specifications prepared

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Table 6. Hardware Utilization List (Cont)

Item Description	M = Make B = Buy G = GFE	Development State: Existing: As Is	Development State: Existing: Modified	Development State: New	Test Hardware Requirements: Breadboard	Structural Static Test Article	Development Test Spacecraft	Qualification Test Spacecraft	Other Test Hardware	Total	WBS Block No	Flight Hardware Requirements: 1 Flt SC: SC Requirements	1 Flt SC: Spares	1 Flt SC: Total	2 Flt SC: SC Requirements	2 Flt SC: Spares	2 Flt SC: Total	WBS Block No	Total Requirements (Tes and Flight): 1 Flight Spacecraft	Total Requirements (Tes and Flight): 2 Flight Spacecraft
Mechanized Devices											1.11							2.11		
High-gain antenna deployment mechanism	M		X				1	1		2		1	1	2	2	1	3		4	5
Low-gain antenna deployment mechanism	M		X				1	1		2		1	1	2	2	1	3		4	5
Solar panel positioning actuators	M		X				4	2		6		2	1	3	4	1	5		9	11
Ground Support Equipment											6.0							6.0		
Solar panel interface checkout unit	M			X			1								1		1		1	2
Ground power supply	B			X			1								1		1		1	2
Battery activation and test unit	B	X						1									0		1	1
Power system checkout unit	M			X			1								1		1		1	2
Flight TM decoder/processor computer	G	X					1								1		1		1	2
Flight command coder	G	X					1								1		1		1	2
CC&S checkout unit	G		X				1								1		1		1	2
Star/sun simulator	B		X				1								1		1		1	2
Gas system checkout and servicing unit	M			X			1								1		1		1	2
G&N electronics checkout unit	M			X			1								1		1		1	2
Pyro simulator set	M		X				1								1		1		1	2
Test stand	M			X			1								1		1		1	2
Qual test instrumentation set	B			X				1		1				0			0		1	1
GSE cable set	M			X			1	1		2		2		2	3		3		4	5
Mockup (Soft)	M										1.13							1.13		

*Preliminary equipment specifications prepared

6.0 PROGRAM COST ESTIMATES

6.1 COST ESTIMATING METHODOLOGY

NR Space Division methodology for estimating cost requirements, applied to the Solar Electric Propulsion Asteroid Belt Mission Program, was designed to meet the program requirements of credibility, accuracy, and timeliness. Basic estimating by "grass roots" was used.

"Grass roots" is defined as follows: each estimating functional organization that would be involved in the subsequent phases of the program estimated their contribution to the program, based on functional work package tasks defined under the Work Breakdown Structure. The detail estimates were prepared by first-line supervisory personnel, reviewed by successive levels of management, and ultimately reviewed and approved by the Study Manager.

Preliminary equipment specifications were prepared and furnished to the Purchasing Department, who obtained estimates for subcontract effort to specification requirements from prospective subcontractors and suppliers. The Hardware Utilization List (Table 6) defines the major components and required quantities.

Labor estimates are categorized by discipline. Engineering, Testing, Manufacturing, etc. Current 1970 dollar values were used.

Figure 1 (Introduction Section - Program Development Plan Approach) shows the steps of the systematic, comprehensive, and detailed approach that NR Space Division used in developing the cost estimates.

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6.2 COST ESTIMATING GROUND RULES AND COVERAGE

The cost estimates include both one- and two-flight spacecraft programs. Significant ground rules and coverage are as follows.

1. Ground Rules

- "Grass roots" approach
- Labor rate based on plant-wide average
- 1970 dollars
- Presently experienced burden rate
- Includes general and administration expense
- No fee or profit included
- Launch and flight operations support (spacecraft only)
- Launch vehicle cost not included
- DSN cost not included
- Minimum requirements for new facilities
- Estimation of costs at major subsystem level
- Identification of development and production costs
- Major variations between one- and two-flight spacecraft programs

2. Coverage

- Hardware, software, services, and other work tasks
- Definition, design, manufacture, test, GSE, and facilities

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6.3 COST ESTIMATES

6.3.1 TOTAL PROGRAM COST SUMMARY

The Total Program Cost Summary is shown in Table 7. It will be noted that the total estimated cost for the one-flight spacecraft program is 59 million dollars. The total estimated cost for the two-flight spacecraft program is 74.5 million dollars, 15.5 million dollars more than for the one-flight program.

6.3.2 IDENTIFICATION OF COST CATEGORIES

The cost categories listed in Table 7 may be identified by reference to the Work Breakdown Structure (Figure 3) as follows.

1. Development

   Phase B -- All WBS items

   Phase C -- All WBS items

   Phase D -- WBS 1.0 Spacecraft Test Hardware
   WBS 4.0 System Engineering and Integration
   WBS 5.0 Facilities
   WBS 6.0 Ground Support Equipment
   WBS 7.0 Tooling and Special Test Equipment

2. Production

   Phase D -- WBS 2.0 Spacecraft Flight Hardware
   WBS 8.0 Logistic Support
   WBS 9.0 Launch Operations Support

3. Flight Operations Support

   Phase D -- WBS 10.0 Flight Operations Support

4. Project Management

   Phase D -- WBS 3.0 Spacecraft Project Management

Table 7. Solar Electric Propulsion Asteroid Belt Mission Program
Total Program Cost Summary

PHASES B, C, AND D	
Category	Cost (Dollars in Millions)
ONE-FLIGHT SPACECRAFT PROGRAM	
Development (system engineering, design, test hardware, testing)	35.4
Production	21.1
Flight operations support	.7
Project management (cost and schedule control, data management, etc.)	1.8
	Total Program $ 59.0
TWO-FLIGHT SPACECRAFT PROGRAM	
Δ Cost (production - Phase D)	$ 15.5
	Total Program 74.5

6.3.3 MANPOWER LOADING REQUIREMENTS

Estimated manpower loading requirements are shown in Figure 28 for Phases B, C, and D (through launch). Peak manpower requirements would be approximately as follows: Phase B-22, Phase C-130, Phase D (through launch, one-flight spacecraft program). 190, and Phase D (through launch, two-flight spacecraft program). 210. Manpower requirements for Flight Operations Support during Phase D after launch would range between a high of about 15 and a low of about 3.

6.3.4 FUNDING REQUIREMENTS

Cumulative funding requirements and funding requirements by Government Fiscal Year Quarter are shown in Figures 29 and 30, respectively, for Phases B, C, and D (through launch). The estimated cost for Phase B is about 490,000 dollars; for Phase C, about 2.6 million dollars, for Phase D (through launch - one flight spacecraft program), about 55.2 million dollars, for Phase D (through launch - two flight spacecraft

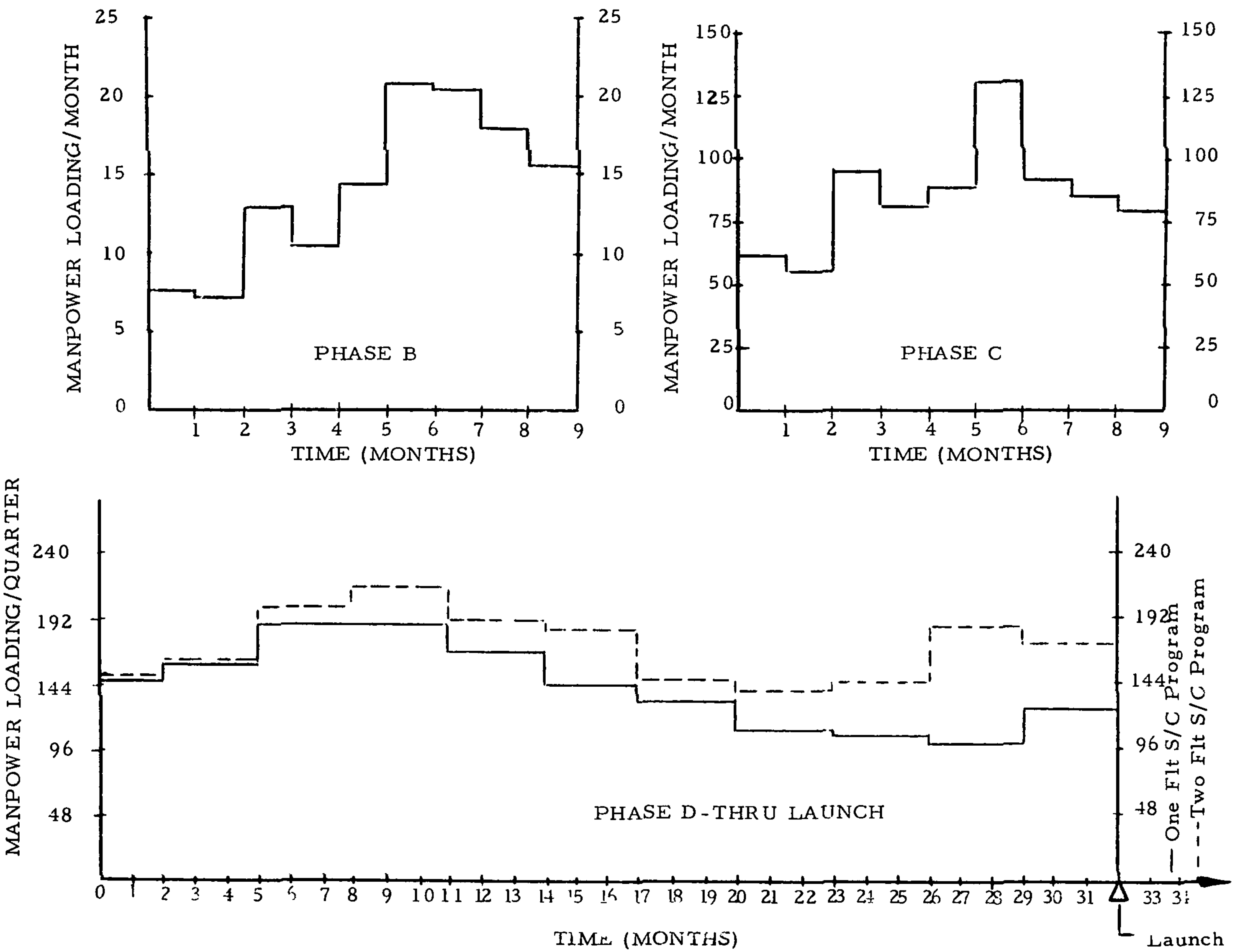

Figure 28. Manpower Loading Requirements

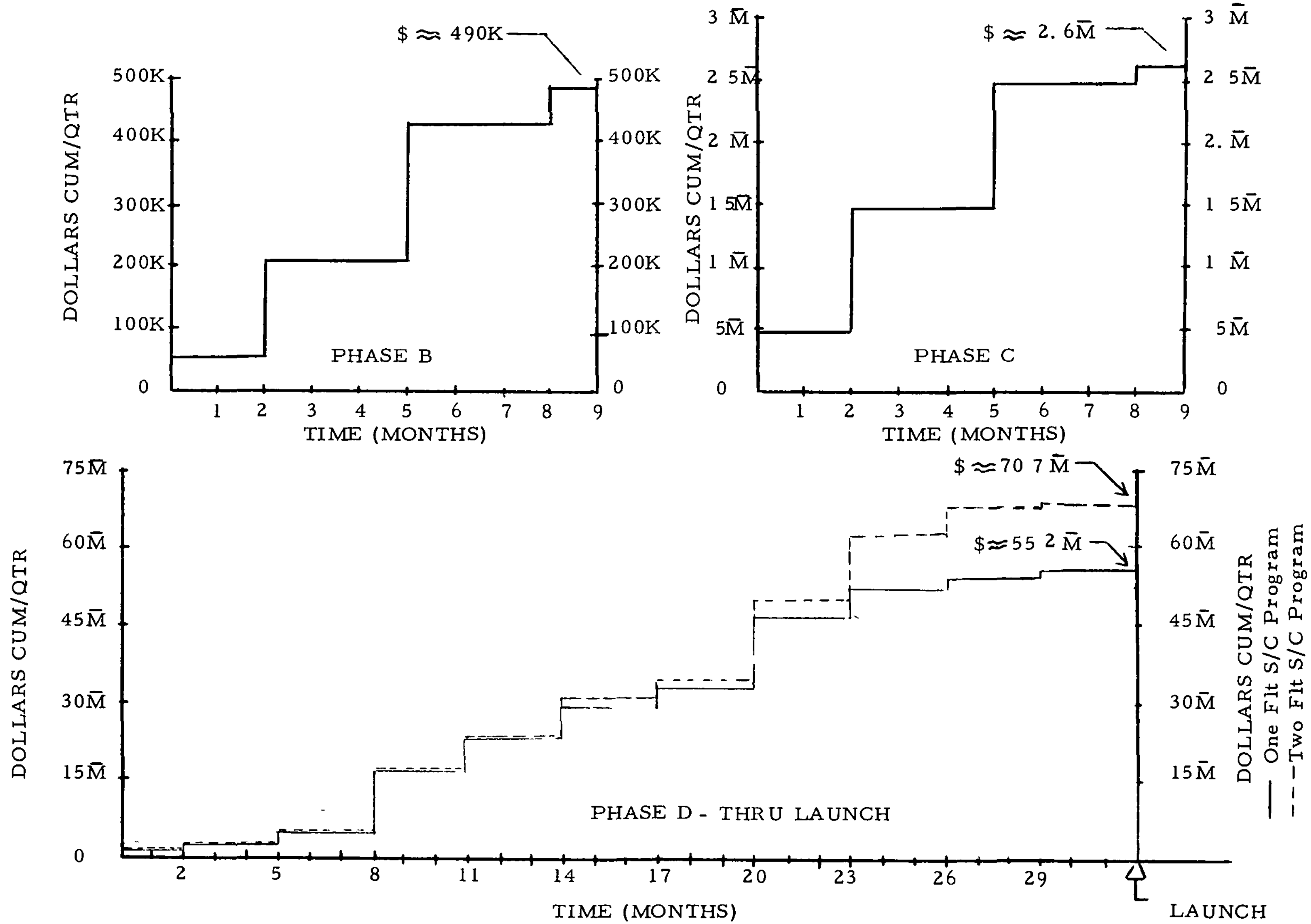

Figure 29. Cumulative Funding Requirements

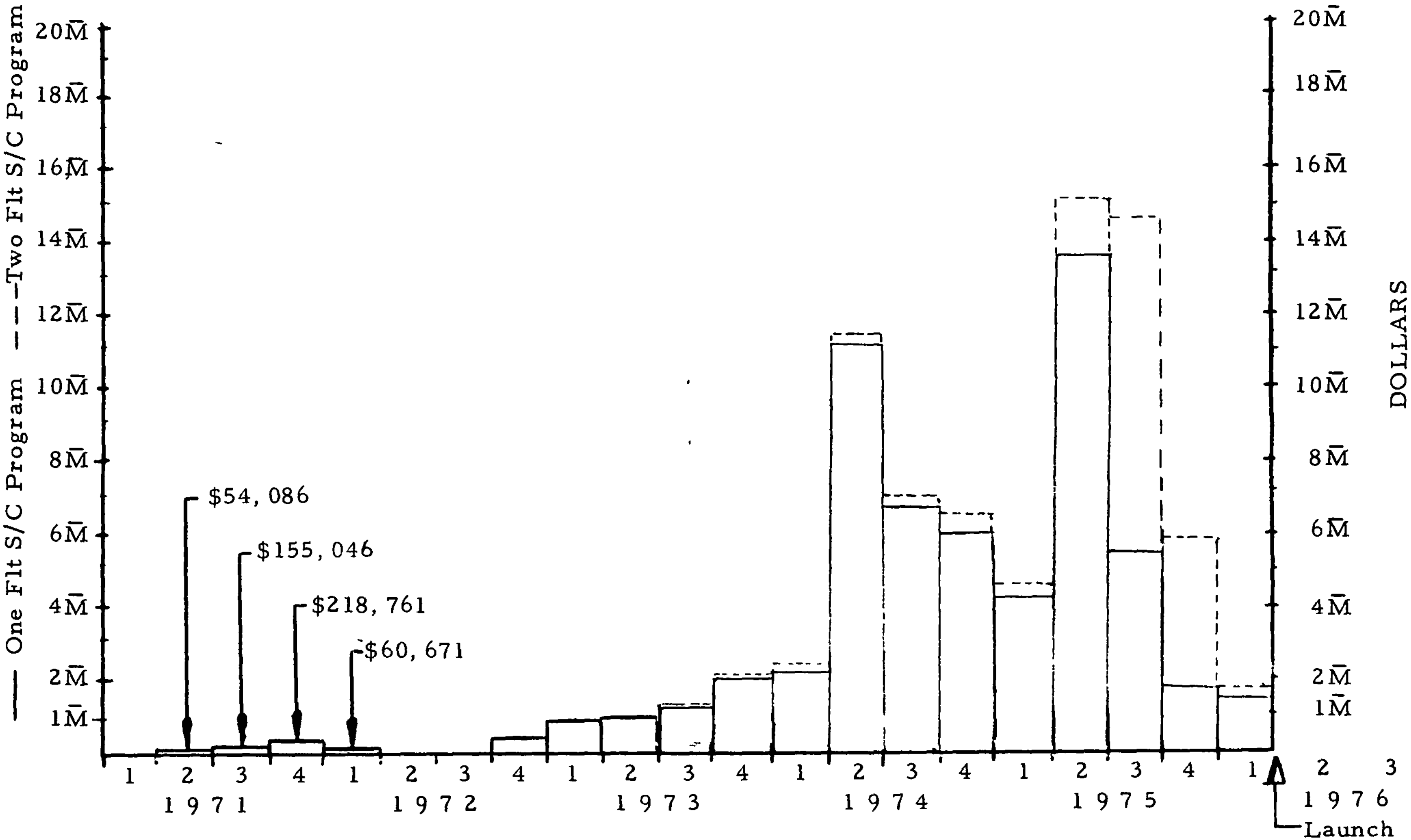

Figure 30. Funding Requirements by GFY Quarter

program), about 70.7 million dollars. The estimated cost for flight operations support is approximately 700,000 dollars. The incremental cost of the second flight spacecraft, therefore, would be about 15.5 million dollars.

6.3.5 COST DISTRIBUTION

The distribution of estimated costs is shown in Table 8 for Phases B, C, and D (through launch - one-flight spacecraft program).

6.3.6 ESTIMATED COSTS TO MAJOR SUBSYSTEM LEVEL

The estimated costs to the major subsystem level are shown in Tables 9 and 10 for the one- and the two-flight spacecraft programs, respectively. The tabulations are by Work Breakdown Structure items (Figure 3).

Table 8. Cost Distribution

	Percent of Total		
Cost Element	Phase B	Phase C	Phase D (Through Launch - One Flight SC)
Engineering (NR/SD)*	69.0	68.0	30.7
Subcontracts	24.0	19.0	58.0
Automatic computation	2.5	1.0	0.3
Plans and project management	2.0	1.0	2.1
Manufacturing	-	5.5	7.7
Facilities	-	-	0.5
Travel and subsistence	1.5	1.5	0.3
Publications	1.0	4.0	0.4
	100.0	100.0	100.0

*Includes management, general and administrative, data control, etc.

Table 9. Summary—Estimated Costs by Work Breakdown Structure and Major Subsystems, One-Flight Spacecraft Program

Estimated Costs by Work Breakdown Structure and Major Subsystems (Dollars in Thousands)			
Total for One			$ 59,040
1.0 Solar Electric Propulsion Spacecraft - Test Hardware		$ 25,448	
1.1 Structure	$ 499		
1.2 Telecommunications and Data Processing	6,458		
1.3 Central Computer and Sequencer	3,108		
1.4 Guidance, Navigation and Control	1,606		
1.5 Spacecraft Power and Cabling	2,038		
1.6 Thermal Control	1,562		
1.7 Electric Propulsion	4,574		
1.8 Roll-up Solar Arrav/Capacitor Detector Assembly	3,640		
1.9 Science	150		
1.10 Pyrotechnic Devices	160		
1.11 Mechanized Devices	116		
1.12 Spacecraft Integration Assembly and Checkout	1,500		
1.13 Soft Mockup	37		
2.0 Solar Electric Propulsion Spacecraft - Flight Hardware		$ 20,071	
2.1 Structure	$ 365		
2.2 Telecommunications and Data Processing	5,995		
2.3 Central Computer and Sequencer	2,850		
2.4 Guidance, Navigation and Control	1,072		
2.5 Spacecraft Power and Cabling	1,135		
2.6 Thermal Control	311		
2.7 Electric Propulsion	1,302		
2.8 Roll-up Solar Array/Capacitor Detector Assembly	5,560		
2.9 Science	76		
2.10 Pyrotechnic Devices	35		
2.11 Mechanized Devices	37		
2.12 Spacecraft Integration Assembly and Checkout	1,333		
3.0 Spacecraft Project Management		$ 2,060	
4.0 System Engineering and Integration (SE&I)		1,934	
5.0 Facilities		1,056	
6.0 Ground Support Equipment		4,165	
7.0 Tooling and Special Test Equipment		2,477	
8.0 Logistics Support		259	
9.0 Launch Operations Support		865	
10.0 Flight Operations Support		705	

Table 10. Summary—Estimated Costs by Work Breakdown Structure and Major Subsystems, Two-Flight Spacecraft Program

Estimated Costs by Work Breakdown Structure and Major Subsystems (Dollars in Thousands)			
Total for Two			$ 74,500
1.0 Solar Electric Propulsion Spacecraft - Test Hardware		$ 25,756	
1.1 Structure	$ 499		
1.2 Telecommunications and Data Processing	6,458		
1.3 Central Computer and Sequencer	3,108		
1.4 Guidance, Navigation and Control	1,606		
1.5 Spacecraft Power and Cabling	2,038		
1.6 Thermal Control	1,562		
1.7 Electric Propulsion	4,574		
1.8 Roll-up Solar Array/Capacitor Detector Assembly	3,640		
1.9 Science	150		
1.10 Pyrotechnic Devices	160		
1.11 Mechanized Devices	116		
1.12 Spacecraft Integration Assembly and Checkout	1,808		
1.13 Soft Mockup	37		
2.0 Solar Electric Propulsion Spacecraft - Flight Hardware		$ 33,230	
2.1 Structure	$ 415		
2.2 Telecommunications and Data Processing	9,710		
2.3 Central Computer and Sequencer	4,267		
2.4 Guidance, Navigation and Control	1,533		
2.5 Spacecraft Power and Cabling	1,812		
2.6 Thermal Control	376		
2.7 Electric Propulsion	2,580		
2.8 Roll-up Solar Array/Capacitor Detector Assembly	10,408		
2.9 Science	76		
2.10 Pyrotechnic Devices	47		
2.11 Mechanized Devices	37		
2.12 Spacecraft Integration Assembly and Checkout	1,969		
3.0 Spacecraft Project Management		$ 2,060	
4.0 System Engineering and Integration (SE&I)		1,968	
5.0 Facilities		1,080	
6.0 Ground Support Equipment		5,000	
7.0 Tooling and Special Test Equipment		2,681	
8.0 Logistics Support		290	
9.0 Launch Operations Support		1,730	
10.0 Flight Operations Support		705	

APPENDIX A

INDUSTRIAL ENGINEERING METHODS AND STANDARDS PLAN

I. MANUFACTURING SUPPORT

An objective of the industrial engineering methods and standards activity will be to provide Manufacturing and Project Management with data based on engineered time standards for total visibility and control of the production effort. The products of this task consist of the following:

1. Engineered time standards based on engineering drawings and specifications for fabrication of details, subassembly buildup, and final assembly operations.

2. A manufacturing sequence-of-work plan which graphically depicts all parallel and sequential manufacturing inspection operations.

3. A computer-produced, detailed breakdown of all manufacturing and inspection tasks, crew size, skills, critical equipment requirements, and standard hours for each task. Each task will be referenced to its authorizing engineering and manufacturing documentation.

Information available from the above products include the following:

1. Specific need dates for parts, tooling, skills, work authorizing documents, etc.

2. Work station manning requirements.

3. Determination of critical path, optimum change integration points, and work-around planning data to minimize schedule delays due to part shortages, functional anomalies, etc.

4. Time standards for cost and schedule evaluation.

5. Basic data for determination of plant layout, station design, and handling requirements.

II. TEST OPERATIONS SUPPORT

The industrial engineering support to the testing activities of the SEP Program will be primarily directed towards preparation of a time-lined sequence of operations based on engineered time standards necessary to prepare the craft for checkout and shipping. This sequence consists of crew and time requirements for test equipment hook-up, installation of simulators and instrumentation, handling, packaging, and transport. It will provide visibility to Test Management of those non-checkout flow times and constraints on a specific test. Schedule and man-load estimates can be derived from this analysis to provide work-around planning information for integration of changes or correction of malfunctions.

APPENDIX B

PRELIMINARY MATERIAL HANDLING AND PARTS PROTECTION PLAN

I. MOCKUP (SOFT)—PHASE C

To verify dimensional and fabrication feasibility and describe to the customer the spacecraft design. Also to investigate the effects of proposed design changes.

No requirement:

II. BREADBOARD(S)—PHASE D

As required by Design Engineering to develop subsystem electrical, mechanical, thermal characteristics. May be accomplished at supplier plant, governed by procurement specifications and/or direction of the subsystem specialist.

No requirement:

To be performed by suppliers.

III. STRUCTURAL STATIC TEST ARTICLE—PHASE D

To verify structural integrity under test conditions simulating maximum boost acceleration, maximum bending moment, and maximum load conditions of the mission. Testing to be conducted on complete structural assembly, including equipment shelf (or shelves) secondary structure. Significant component weights and cg's will be simulated, and loads will be applied through attach points.

IV. DEVELOPMENT TEST SPACECRAFT (PROTOTYPE)—PHASE D

To provide early evaluation of potentially critical conditions caused by the ground test, launch, and mission environments; utilized to confirm analytic techniques and get supplemental data; provide gross design verification of weight and balance, vibration, acoustic and thermal balance.

Quantity			
One	Two	Number	Equipment
B/1 PRIMARY STRUCTURE			
1	1	9EH-10001	Rack, frame parts
1	1	9EH-10002	Dolly, trunnion for assembly and transport
1	1	9EH-10014	Work stand, assembly and installation
1	1	*9EH-10012	Sling, assembly
B/290 ASSEMBLY			
1	1	9EH-10003	Sling
1	1	9EH-10004	Sling
1	1	9EH-10005	Sling
1	1	9EH-10006	Sling
1	1	9EH-10007	Sling
			Existing Rueger hydraulic portable jib crane
OFFSITE ENVIRONMENTAL VACUUM CHAMBER			
1	1	9EH-10013	Cover
1	1	9EH-10008	Sling, test operations
1	1	9EH-10010	Carriage, assembly for vacuum chamber
1	1	9EH-10009	Dolly, to accept 9EH-10010
1	1	9EH-1216	Trailer, special transport
14	14		
*Could use 9EH-10008			

V. QUALIFICATION TEST SPACECRAFT—PHASE D

Required to provide assurance that the flight spacecraft will perform in accordance with established criteria for ground test, launch, and mission performance. Will be built to the same configuration of structures and subsystems as that of a flight spacecraft.

Quantity			
One	Two	Number	Equipment
B/1 STRUCTURAL ASSEMBLY			
-	-	9EH-10001	Rack
1	1	9EH-10002	Dolly
-	-	9EH-10012	Sling
1	1	9EH-10014	Work stand
B/290 ASSEMBLY			
-	-	9EH-10003	Sling
-	-	9EH-10004	Sling
-	-	9EH-10005	Sling
-	-	9EH-10006	Sling
-	-	9EH-10007	Sling
OFFSITE ENVIRONMENTAL VACUUM CHAMBER			
-	-	9EH-10008	Sling
-	-	9EH-10010	Carriage
-	-	9EH-10009	Dolly
-	-	9EH-1216	Trailer
STORAGE			
1	-	9EH-10013	Environmental cover
3	2		

VI. FLIGHT SPACECRAFT

The spacecraft concept evolved during this study consists of a 7.8-kw electric propulsion system spacecraft launched on the Atlas/Centaur launch vehicle. It utilizes two pairs of modified GE roll-out solar cell panels. The total power available at 1 AU is 10.0 kw. Degradation due to radiation and meteoroid damage is assumed to be 15 percent and 1 percent, respectively. Losses were estimated at 2 percent. A constant requirement for approximately 400 watts is assumed for spacecraft subsystem and science payload during the thrusting phase. This leaves 7.8 kw for the electric propulsion system at 1 AU.

Quantity		Number	Equipment
One	Two		
B/1 STRUCTURAL ASSEMBLY			
-	-	9EH-10001	Rack
1	2	9EH-10002	Dolly
-	1	9EH-10008	Sling
B/290 ASSEMBLY			
-	-	9EH-10003	Sling
-	-	9EH-10004	Sling
-	-	9EH-10005	Sling
-	-	9EH-10006	Sling
-	-	9EH-10007	Sling
OFFSITE ENVIRONMENTAL VACUUM TEST			
-	-	9EH-10008	Sling
-	-	9EH-10010	Carriage
-	-	9EH-10009	Dolly
-	-	9EH-1216	Trailer
STORAGE			
-	1	9EH-10013	Environmental cover
1	4		

APPENDIX C

AVAILABLE FACILITIES

The facilities are grouped in the following three basic activity areas:

Administration and Engineering Offices

Production Facilities

Laboratories and Test Facilities

ADMINISTRATION AND ENGINEERING OFFICES

Project management and engineering personnel could be located in Company-owned Building 2, which is also headquarters for the management and technical staff of Research, Engineering and Test and Advanced Programs Divisions. Proximity of Building 2 to the Computer Center and other support areas would facilitate communications and would allow concentration and control of effort on the project. One IBM 360 Model 20 satellite computer is available in Building 2 for remote entry into the IBM 360-50/65 ASP (attached support processor) system.

PRODUCTION FACILITIES

Detail parts, components, and structural members for the basic structures of test vehicles and flight articles could be fabricated and assembled in Building 1, Downey. Components for the systems, not obtained from subcontractors, also would be fabricated in this facility. Final installation of systems and components onto the basic structure and subsequent checkout would be accomplished in environmentally controlled areas of Building 290. For safety purposes, proof-pressure and leakage tests of pneumatic systems would be conducted in environmentally controlled test cells of Building 289.

The fabrication and assembly of the soft mockup would be accomplished in Company-owned Building 18, Downey. The Engineering support shop provides Space Division's engineering groups with the fabrication of mockups, test articles, first articles, models, and prototypes and assists in the development of new designs and fabrication techniques. This shop, part of Manufacturing, is operated primarily to support engineering projects that require highly specialized equipment and skills. The department has

three major sections: the machine shop, sheet metal shop, and wood shop. The department also has plastics, welding, and electronics fabrication capabilities. The shop has more than 50 items of modern equipment and highly-trained workers capable of conducting an integrated engineering-manufacturing program which conforms with specific quality assurance and program control procedures.

LABORATORIES AND TEST FACILITIES

In the Laboratories and Test Facilities, special equipment and experienced personnel with extensive laboratory testing backgrounds make possible all types of developmental testing. This capability covers materials, processes, and structural and dynamic testing. Instrumentation and computation groups are used to provide rapid recording and interpretation of data. Affiliated design and fabrication groups expedite the production and deployment of test apparatus.

Activities utilizing these facilities can be divided into two groups: design criteria development, and design verification and engineering qualification. The laboratory complex in Building 1, the materials and processes facilities, and the radiation laboratory in Building 4 would provide data required by Engineering to establish design parameters. Design verification and engineering qualification include tests conducted in the dynamic simulation, climatics, thermal simulation, vacuum and structural test areas in Building 288, pressurization system development facility in Building 299, and acoustic facility in Building 260 of the Los Angeles Division.

1. Computing and Data Systems Services, Building 4 - Space Division's Digital Computing and Data Processing Center is located in Company-owned Building 4. This facility also houses the Simulation Center which is equipped with analog computers and a portion of the Division's research laboratories. Digital computers available to this program would include four IBM 360 Model 20's, two IBM 360 Model 30's, two IBM 360 Model 50's, and three IBM 360 Model 65's. There is also a Stromberg-Carlson 4020 CRT optical or graphical plotter and an IBM Model 2250 graphic display station.

2. Radiation Laboratory, Building 4 - Environmental Control/ Space Radiation Laboratory provides a means of measuring sample charges when objects are subjected to various types of particle bombardments while in a 10^{-6} torr environment. Radiation sources include ion, proton, OV, and a 4-inch beam solar simulator.

3. Electrical-Electronics, Building 1 - This laboratory has research and development capabilities certification testing capabilities, as well as the ability to service and condition electrical and electronic devices including those of electromagnetic, electrochemical, and electromechanical origin. The electrical insulating capabilities extend from wiring to complex molding and encapsulation of assemblies. Certification tests can be run on components of complete systems whether generating or storing energy, or converting, distributing, sensing, sequencing, or controlling electrical energy. Malfunction analysis, verification tests, and functional studies can be performed in these laboratories on pneumatic and hydraulic components and systems. These laboratories are equipped for conducting extensive hydrodynamic tests.

4. Dynamic Simulation, Building 288 - Equipment capable of dynamic simulation is located in Building 288 (see Table C-1).

5. Thermal Simulation, Building 288 - This facility contains 36 channels of radiant heating control computers and ignitron power controllers, a transformer vault rated at 6,000 kva continuous and approximately 7,250 kva for five minutes, one 36-channel remote control console, an 8-channel parallel-entry digital temperature recording system, and miscellaneous multiple-channel recycling temperature and output voltage recorders. This facility can simulate boost as well as earth and planetary entry conditions of aerodynamic heating and/or shear. Heat transfer and material studies for very high temperature testing, in vacuum or inert atmosphere, can also be accomplished. Research and development testing on thermal testing devices can also be performed.

6. Vacuum, Building 288 - The Vacuum Facility contains specialized test equipment for subjecting spacecraft hardware and materials to combined space environment including high vacuum (10^{-4} to 10^{-11} torr), solar radiation, and temperature extremes.

7. Structural Test, Building 288 - The Structural Test Facility in the Space Systems Development Facility in Building 288 covers approximately 14,400 square feet. Imbedded in the floor of this area on 4-foot spacings are 39 floor beams that are 60-feet long and have a capability of reacting 75,000 pounds for each 10 feet of length. Two 5-ton capacity overhead cranes with hook heights of 35 feet can cover the entire floor area. Four test columns, 24 feet high, are located near the north wall of the facility. Each column has a capability of reacting 10,000 inch-pounds of moment.

Table C-1. Dynamic Simulation, NR Space Division
Building 288

Force	Frequency Range
Hydraulic, 100,000 pounds	0 to 500 cps
Electrodynamic, 30,000 pounds	5 to 2,000 cps
(Lone-MB), 3,500 pounds	5 to 2,000 cps
Random and sine wave, 7,000 pounds	5 to 3,000 cps
Random and sine wave, 8,000 pounds	5 to 3,000 cps (HF)
Random and sine wave, 10,000 pounds	5 to 2,500 cps
Random and sine wave, 10,000 pounds	5 to 3,000 cps
Line-MBO, 1,200 cps	5 to 3,000 cps
High-force thruster, 60,000 pounds	5 to 2,000 cps
Multishaker array - capability in excess of 60,000 pounds force.	

8. Pressurization System Development Facility, Building 299 - The proof-pressure, leak, and developmental testing is planned to be performed in the Pressurization System Development Facility, Building 299. The specified tests will be performed in one of the three test cells. The test cells are utilized for proof-pressure, leakage, and performance evaluation of components, subsystems, and GSE end items at operational temperatures. The facility has pressure systems up to

20 pounds per second at 20,000 psi. Safety is emphasized throughout the facility. The building is separated from other facilities and is designed for hazardous operations. Test cell walls are 12-inch-thick concrete, capable of withstanding an energy release equivalent to ten pounds of TNT. Observation windows between the instrument room and test cells are made of bullet-resistant glass and have steel crossbars for additional protection. Comprehensive procedures and warning systems ensure safe and proper handling, transfer, and utilization of pressurized gases and liquid nitrogen.

9. EMI/RFI Testing, Building 1 (Pictures 833-1810 and 7006-74-33A) - The screen room (16 feet by 52 feet by 10 feet) is located in the Communications and Controls Facility, Building 1. The room is equipped for the complete range of electromagnetic and radio frequency interference testing. All equipment necessary to detect electronic signals and convert these signals to visual displays is available. With the equipment and personnel available, this facility can handle all tasks from initial bread-boarding concepts through development and final checkout of the finished component system.

10. Los Angeles Division Acoustic Test Laboratory, Building 260 - The sonic test laboratory is capable of generating narrow-band, discrete frequencies from 25 to 10,000 cps at sound intensities up to 170 db over a three-foot area and at intensities of 160 db in a reverberant room 10 feet by 14 feet by 25 feet. Random noise can be generated at a frequency spectrum from 15 to 12,800 cps with an overall sound pressure level of 176 db over a three-foot area and 161 db in the reverberant room. Measurement, recording, and analysis systems necessary for acoustic test programs are available in the laboratory.

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APPENDIX D

ELECTRIC PROPULSION SYSTEM DEVELOPMENT PLANS

INTRODUCTION

Appendix D pertains to the electric propulsion system (EPS) development plans and was prepared by Hughes Research Laboratory as part of their study effort on the program. The EPS development plans were prepared in a thoroughly integrated manner with the rest of the Program Development Plan (i.e., Work Breakdown Structure, Figure 3, Items 1.7 and 2.7; Program Development Schedule, Figure 4, Electric Propulsion System Development; Subsidiary Program Plans; Hardware Utilization List and Program Cost Estimates).

SCHEDULE

Figure D-7 (page 171) is the electric propulsion system hardware schedule. Delivery dates for hardware components are consistent with the requirements for spacecraft system integration, assembly, and checkout of the test and flight spacecraft, as shown on the overall Program Development Schedule (Figure 4).

DEVELOPMENT PLANS

Part 1 - Engineering Plan

Purpose

This plan covers the various engineering activities associated with the development of an electric propulsion system, i.e., thruster and feed system, translator and feed system, thruster gimbals, power conditioning and control system, propellant reservoir and manifolding, ancillary con-controls and switching networks complete with integration and test requirements for Phases B, C, and D.

Scope

The Propulsion and Power Systems Laboratory of the Engineering Laboratories, Space Systems Division, will be responsible for the electric propulsion system for the solar electric propulsion asteroid belt spacecraft.

Engineering project control for this development effort will be established and maintained within the Engineering Laboratories located in the HAC Space Division in El Segundo, California.

Detail design and development responsibility for the key elements of this propulsion system will be as follows:

Hughes Aircraft Company, Research Laboratories - Thruster and propellant feed system
North American Rockwell, Space Division - Propulsion module structure, gimbals and translator components
Hughes Aircraft Company, Space Systems Division - Power conditioning, ancillary electronics, final assembly integration and subsystem testing

Effective project management requires excellent planning, visibility, coupled with effective control. To execute such a project, all objectives will be clearly defined with the effort divided into a logical work breakdown structure. The increment of work will be defined to be time-phased in a manner that allows the major milestones to be accomplished at the proper time. The work breakdown structure for electric propulsion system development is shown in Figure D-1. Time-phasing is exemplified in Figure D-2 for the power conditioner and control system.

The management approach for the electric propulsion system features a strong project office, a close interface working relationship, reliance on established configuration and project control techniques, and the use of subcontractors and vendors with experience on previous Hughes satellite projects. The project office has been structured with short lines of authority and responsibility to each area of effort. This clear delineation of authority permits management to reach timely decisions for direction, integration, and control of the projects.

Detailed subsystem design is the responsibility of functional organizations having specialized technological capabilities. The project office controls the system design through the preparation and maintenance of subsystem and interface specifications, design reviews, components and material controls, and direct authority over all design, development, fabrication, and test. The apportionment of responsibility between the supporting organizations and the project office permits the project manager to act quickly and effectively in implementing the design and manufacturing programs. He maintains visibility of the total effort through using established management techniques, informal meetings with project personnel, design reviews, technical status reports, progress reports, and weekly project staff meetings.

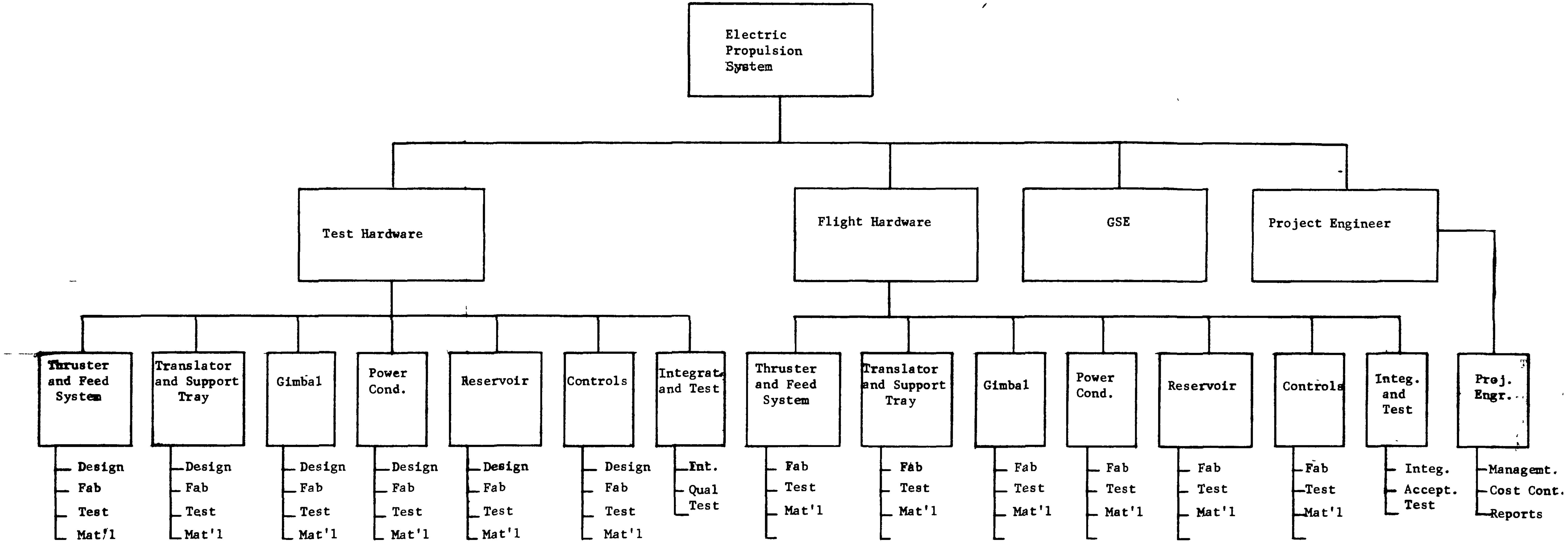
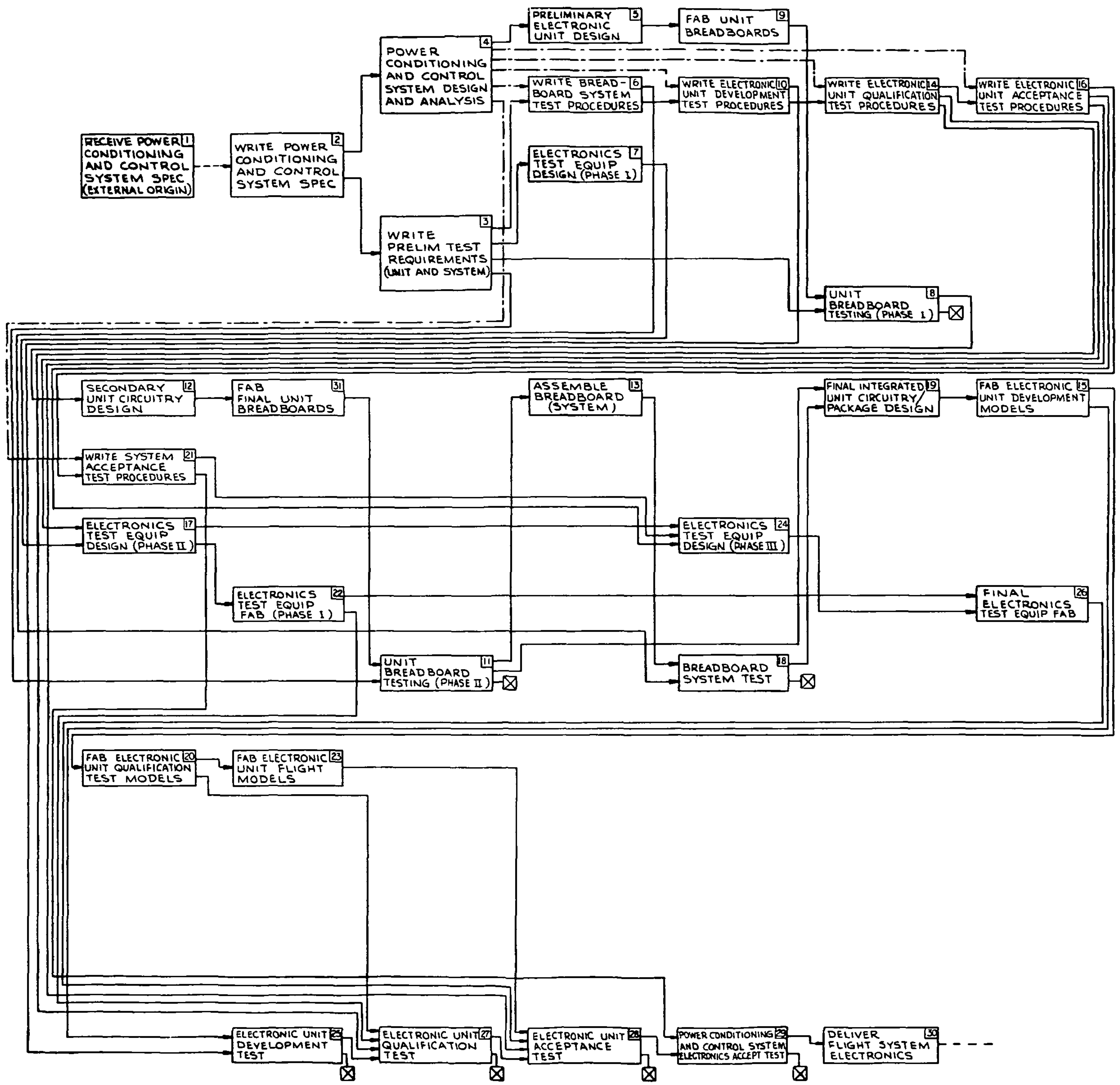


Figure D-1. Electric Propulsion System Development Work Breakdown Structure



DEFINITION OF KEY EVENTS

7 Electronics Test Equipment Design (Phase I)
Preliminary unit and system test equipment design utilizing preliminary test requirements

8 Unit Breadboard Testing (Phase I)
Functional evaluation of selected concepts under laboratory conditions
Preliminary thermal evaluation where applicable

11 Unit Breadboard Testing (Phase II)
Functional evaluation of final unit breadboard models prior to assembly into system configuration

17 Electronics Test Equipment Design (Phase II)
Detailed design phase utilizing formal test requirements through the unit qual test level

18 Breadboard System Test
Functional checkout of the integrated system at the breadboard level
The purpose of this testing is to verify total electrical performance under ambient conditions

22 Electronics Test Equipment Fabrication (Phase I)
Initial fabrication stage with primary emphasis on producing equipment required for unit qualification tests

24 Electronics Test Equipment Design (Phase III)
Final design stage utilizing system test requirements

25 Electronic Unit Development Tests
Performance mapping including determination of operational limitations where applicable *Testing shall include* thermal vacuum EMI and subjection to launch mechanical environment Testing shall incorporate the use of test equipment produced through event 22

26 Final Electronics Test Equipment Fabrication
Final fabrication stage with emphasis on completion of equipment applicable to both unit and system testing

27 Electronic Unit Qual. Test
Formal comprehensive functional and environmental evaluation at the prototype unit level Testing shall include thermal vacuum EMI and subjection to launch mechanical environment

28 Electronic Unit Acceptance Test
Formal functional and environmental testing of each flight unit and spare to insure specification compliance

29 Flight Power System Acceptance Test
Formal testing of each flight electronic unit and spare assembled into a mission sequence simulation and shall incorporate the use of a flight type battery

TIME CONSTRAINED FLOW
INFORMATION FLOW ONLY, NO TIME CONSTRAINT
ZERO TIME FLOW
⊠ DENOTES INFORMATION FEEDBACK TO EVENT 4

FIG 2
FLOW CHART – POWER CONDITIONING AND CONTROL SYSTEM DEVELOPMENT, FABRICATION AND TEST

Figure D-2. Power Conditioner and Control System Time-Phase Network

In support of the project office will be the pertinent technical capabilities of Divisions 26, 27 and 30, as shown in Figure D-3. These specialized activities are in support of the project office operating within the Division 22 Engineering Laboratories as shown in Figure D-4.

The project office contains all the skills necessary for:

Technical direction and integration, configuration management, subcontractor management, project cost, and schedule control

The complete engineering and manufacturing cost, schedule, and performance control of subsystem project engineering in supporting organizations

Closed-loop regulatory controls operating through all supporting organizations and made possible by centralized cost accumulation, PERT/time/cost, hardware fabrication, production control, and quality control

Task Descriptions

Phase B (Definition). The conceptual design of the Electric Propulsion System established in this study, considered as Phase A, serves as the baseline for engineering development to be initiated in Phase B. In Phase B, the design parameters will be intensively analyzed to determine reasonably specific design limits for a preliminary system definition with compatible interfaces among the propulsion system components and also with the other major spacecraft systems. Subsystem design requirements will be generated early in Phase B to define the physical design characteristics such as shape, weight, volume, etc., and the functional design criteria such as power levels, voltages, duty cycles, environmental requirements, reliability and interface data.

Throughout the Phase B development effort, close technical and managerial liaison will be maintained by the electric propulsion system project manager and his staff by means of frequent informal design conferences augmented by formal design reviews to be held at critical milsteone points of the schedule with the spacecraft systems integration contractor.

The planned output of Phase B will consist of a preliminary system definition which will include the following elements:

Block diagrams to show functional relationship and mutual interfaces of the various subsystems of the electric propulsion system

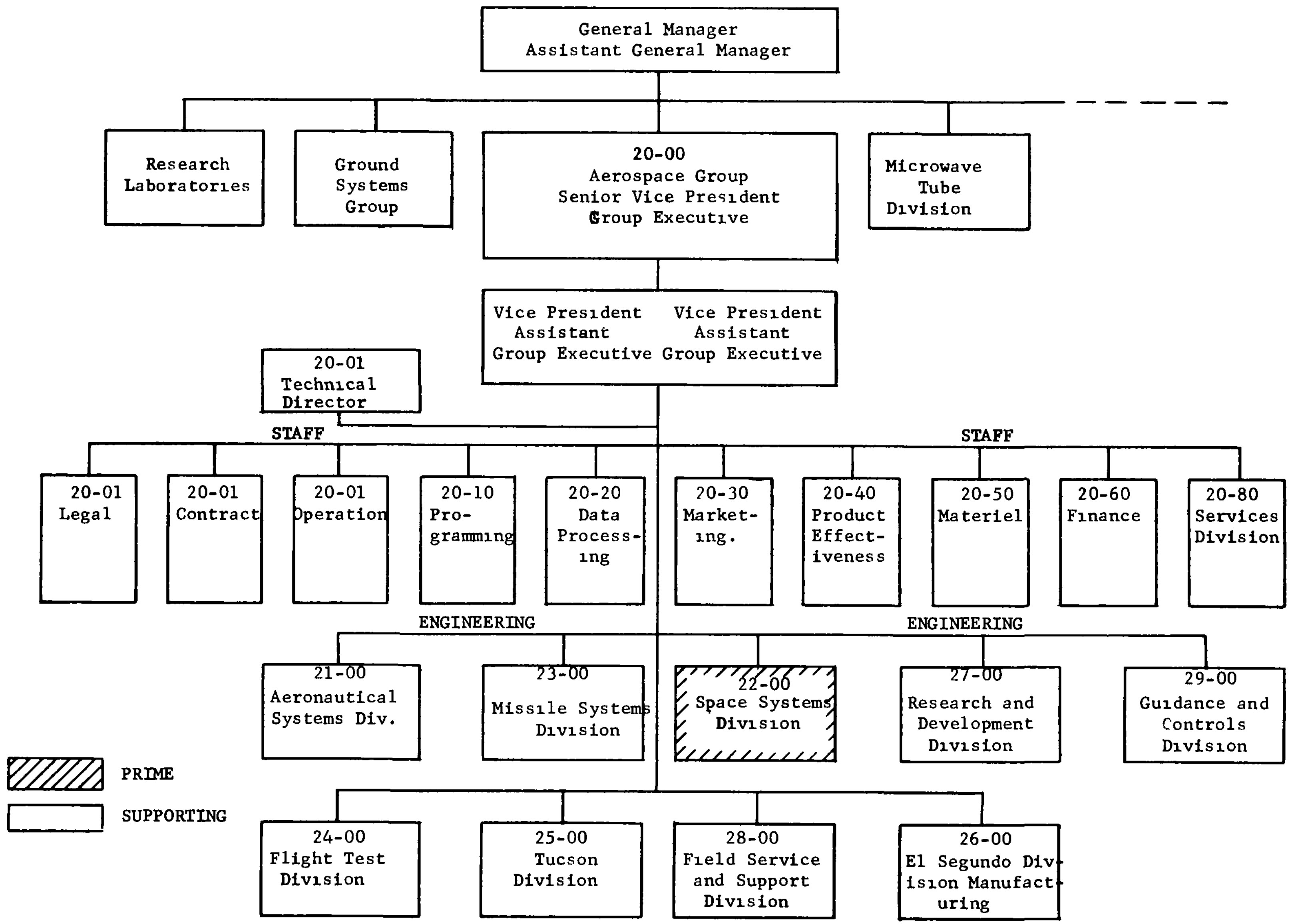


Figure D-3. Hughes Aircraft Company Organization

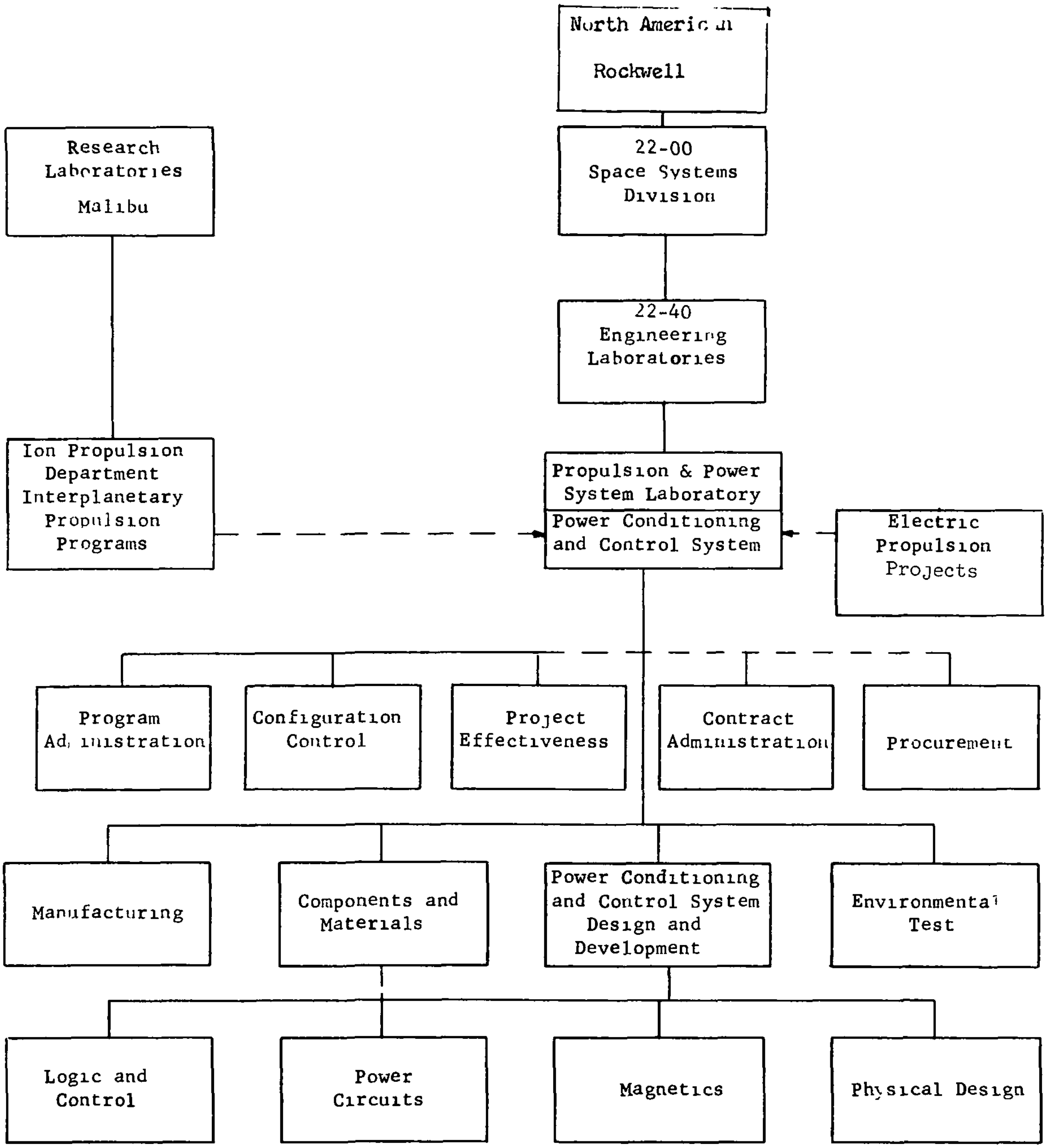


Figure D-4. Electric Propulsion System Project Management Organization

Block diagrams to show functional relationship and interface data between the electric propulsion system and the spacecraft

Preliminary design drawings and preliminary technical descriptive data for each major subsystem

Identification and summary description of any units or components currently within the state of the art but which require specific design, development or qualification

Summary statement of testing philosophy

It is anticipated that the preliminary design data generated during Phase B will be approved with minor modifications and will constitute the baseline design for Phase C. The detailed Statement of Work for Phase C will be generated in accordance with the revised requirements and schedules. Detailed design requirements for each subsystem will be established by the project office to provide specific guidelines for each subsystem area.

One of the major elements of preparing a detailed design of a complex system for space applications is the selection of the optimum components, parts, materials and fabrication techniques which will provide the best combination of reliability, performance and cost-effectiveness.

Phase C (Design). The major engineering end items of Phase C will consist of a complete set of manufacturing drawings of all hardware elements of the system. No subcontract procurement is currently foreseen for this project. However, in case that such a requirement should develop, a complete set of procurement specifications will be developed for use during Phase D. In addition to the descriptive drawings, a full set of subsystem and system specifications will be prepared. During this phase, the detailed plans to be implemented during development/operations (Phase D) would be prepared. Phase C may involve breadboarding of some of the propulsion system elements to insure meeting Phase D delivery schedules.

Phase D (Development/Operations). The primary engineering function of Phase D will be updating of the detailed system design prepared in Phase C, preparation of an advance bill of material, timely release of updated manufacturing drawings to manufacturing, processing of engineering changes, engineering analysis of problem areas, and the analytical evaluation of test results.

Although the major engineering effort of this project will have been completed in Phase C, experience on many other space and defense programs has indicated a definite requirement for the continued existence of

a moderate-sized, experienced engineering staff to provide an immediate reaction capability for the prompt solution of unforeseen problems which generally arise during the initial production phase of a program. The electric propulsion system subcontractor will maintain such an engineering capability until the design integrity of the system is conclusively demonstrated by the development and qualification testing of the system. At this point, the engineering staff may be reduced.

Power Conditioning and Control System Development Plan

Functional Description

The primary function of the power conditioning and control system is to deliver power to the 30-centimeter thruster in the various forms required, and as required by ground command. This requires conversion of the primary power from a solar array to the various voltage and current requirements of the thruster, and approximating 3.9 kilowatts of conditioned power, ranging from low voltage ac to high voltage dc, regulated for a variation in solar array voltages, and controlled over a wide range to maintain and vary thrust.

Control Logic. Operating the thruster in a mode for maximum fuel-utilization and controllable thrust requires closed-loop coupling between various supplies. The necessary sequencing and programming on turn-on and recycle after high voltage arcs and the use of a staggered-phase technique puts a high premium on the use of integrated microcircuits in the control section.

Hardware Composition

The hardware composition of the power conditioning and control system is shown in Table D-1. The estimated gross weight of the system is 36 pounds.

Similarity to Previous Designs

The design concept for the power conditioning and control system for this mission is similar to three systems previously designed and built by the Hughes Aircraft Company. The three systems are briefly described below.

JPL Contract 952229. This system was designed and built for the JPL 20-centimeter thruster that required 2.9 kilowatts of conditioned power, with a line voltage variation from 72 to 80 volts. This thruster was designed using an oxide cathode.

Table D-1. Power Conditioner Composition

Item	Quantity
Control and telemetry module	1
Master oscillator module	1
Low-voltage connector module	1
2.4-kHz power supply module	1
Screen-inverter module	11
Arc-inverter module	3
Line regulator and 5-kHz inverter module	1
Arc-rectifier filter module	1
Magnetic module	2
Accelerator-inverter module	1
High-voltage filter module	1
Chassis and cover	1

During a development period to optimize the thruster mode of operation, more than 700 hours of particularly abusive time was experienced with the thruster. Many thousands of high voltage arcs were experienced without failure during normal operations. This system used center-tap inverters, which would be proposed for a 40- to 80-volt solar array.

JPL Contract 952297. This system was also designed and built for a 20-centimeter thruster, but it was designed for operation with a solar-array line voltage varying from 40 to 80 volts. Over 1,200 hours of operation with the thruster has been logged without failure, except for minor inadvertent standby switching. This anomaly has been corrected by use of a few small RF filter chokes on the logic supply buses.

Hughes Funded. A third power conditioning and control system was designed and built with Hughes Aircraft Company funds for use in testing the Lewis 30-centimeter thruster. This thruster required 300 kilowatts in the main beam, and 1,200 watts maximum in the arc (discharge) supply, the latter for experimental purposes. These supply units operated on a line voltage that could vary from 250 to 500 volts. This system used bridge inverters which would be proposed for a line voltage from 120 to 180 volts.

Make or Buy

Electronic components will be procured with the fabrication of the main frames, covers, and module chassis being subcontracted. All other fabrication and assembly will be performed by HAC.

Special Processes, Materials, or Components

There are no anticipated special processes, materials, or components required. Special magnetics will be designed and fabricated at HAC.

Procurement Considerations, Problems, or Risks

There are no anticipated long-lead-time items which could stress the development and manufacturing schedules.

Fabrication Considerations, Problems, or Risks

A physical design philosophy has been developed as a result of previously designed power conditioners.

The design philosophy described for a space power supply system results from the unique requirements of an electric propulsion power conditioner. Areas of principal concern are thermal control, structure, choice of materials, packaging techniques, high voltage technology and system operation.

Thermal control optimization studies resulted in a power conditioner which is thermally independent of the spacecraft structure. A desirable feature for integration with a spacecraft. The structure is configured such that one side is used as a thermal radiating surface to space and the other provides a mounting surface for all electronics. Special component-mounting techniques and modularization simplify the thermal control problem. Modularization allows for a large number of low-power modules, thus providing uniform heat distribution over the radiating surface.

Structural design will take advantage of the modular concept to reduce the frame or housing weight to a minimum. Each module when mounted provides much of the structural integrity of the system. Special attention has been given to EMI shielding for electronics and harnessing in the form of perforated covers and structure configuration.

State-of-the-art materials were necessarily selected and used because of the unique and stringent requirements imposed on such a power supply system. Metals with high strength, low weight, and good thermal conductivity are used for the structure.

Packaging concepts range from high-density packaging for low-power circuits to distributed components for high-power circuits.

Special attention has been given to high-voltage technology. Transformer and rectifier design for high-voltage, high-current applications takes into account several trade-offs which yield the optimum design for a power conditioner of this type.

Simple tooling will be required by the subcontractors in the fabrication and assembly of the main frames, covers, and module chassis.

Simple vacuum-formed molds, and bobbin mandrels will be required by HAC for the fabrication of the magnetics.

No other special tooling is anticipated, nor are unusual risks foreseen.

Test Considerations, Problems, or Risks

The test program for the Power Conditioning and Control System will consist of:

Development Tests. Individual modules will be subjected to thermal vacuum, vibration, efficiency, and voltage regulation and control tests. Additionally, an integrated system test will be performed, in which the system will be subjected to thermal vacuum, vibration, EMI, voltage regulation and control, and calorimetric efficiency tests.

Qualification Tests. Extensive systems testing to qualification levels will be conducted, in which the prototype will be subjected to thermal vacuum, vibration, EMI, voltage regulation and control, and calorimetric efficiency tests.

Acceptance Tests. Unit and system acceptance testing will be conducted, in which the equipment will be subjected to thermal vacuum, reduced vibration levels, and EMI tests.

Equipment Requirement to Support Fabrication and Test

No special test equipment will be required to support fabrication.

The testing of the power conditioning and control system, at both unit and systems levels, during the development, qualification, and acceptance-test phases, will require the design, fabrication and assembly of special test consoles by HAC. These test consoles will provide simulated vehicle commands, solar array prime power, recording of telemetry outputs, and the measurement of control and regulation with variable loads and variable solar array voltages. Also, thruster high voltage arcs will be simulated.

A discussion of the test consoles, based on test consoles previously designed and built by HAC is presented below:

Power Conditioner Systems Test Console. The test console is used to operate, test, and evaluate the power conditioner during development, qualification, and integration with an ion engine.

It includes the following basic functions.

Simulated loads for the power conditioner. Each of the power supplies are terminated in the correct impedance to operate the power conditioner and evaluate performance. In addition to the normal operating load levels, an open or shorted output can be applied to any power supply output.

Power input to the power conditioner power supplies Four power supplies provide simulated solar panel power to the power conditioner. An array of switches applies and removes power from each group of inverters. A single master switch will remove all power. Selector switches are provided to remove power from individual inverters to simulate failures and demonstrate the ability of the control logic to sense a failure and switch to the redundant or standby inverter.

Instrumentation for monitoring voltage, current, waveform, and temperature: All instrumentation consists of standard commercial equipment. All pertinent voltages, current, and waveforms can be selected and displayed on the appropriate digital voltmeter, RMS voltmeter, and/or scope.

Continual telemetry monitoring: All telemetry outputs are terminated and individually monitored at all times.

The command generator provides control commands to the power conditioner. Command status is displayed by lights on the status panel. An analog command is also provided where necessary.

The arc test will short any two supplies or any supply and ground by a thyratron discharge when so commanded. There are also provisions to apply a direct short or external resistance between any two supplies or any supply and ground. All loads for the power conditioner are provided by the test console, or transferred to the ion engine by the test console.

Power Conditioner and Unit Test Console. A simplified version of the above described test console would constitute the power conditioner checkout and unit test console. The modified test console will have the capability of providing simulated solar panel power, commands, telemetry, and fixed loads to either individual modules or the entire power supply system. This test console will be used during the fabrication and test of individual modules and subsystems. Also, it will be used after the qualification of each power conditioner for verifying operation.

Calorimeter A requirement for measuring accurately the overall efficiency of a complex power supply system has prompted the development of an isothermal calorimeter. Development of this calorimeter was supported by JPL under contract 952297.

The calorimeter is of the isothermal type which indicates heat generation by measuring the rate of boil-off of a liquid. The liquid used is one of the freons (usually freon 11 or freon TF) because of their low toxicity, nonflammability, and nonconductance. The item under test is placed inside the inner chamber of the calorimeter. This chamber and the surrounding one are filled with freon. A hole in the bottom of the inner chamber connects the freon in the outer chamber with that in the inner one. The freon in both chambers is maintained at the boiling point with heaters mounted in the chambers so that any additional heat input to the system, such as that from the item being tested, will be seen as an increase in the volume of the vapor. The reason for the outer chamber of freon is to serve as a thermal insulator for the test chamber. The freon vapor from both chambers is condensed and returned to the outer chamber.

The vapor produced in the inner chamber goes through a small orifice in the lid and into the vapor space in the outer chamber before going to the condensor. A sensitive differential pressure transducer, located on the lid to the inner chamber, senses the pressure difference between the inner and outer chambers caused by freon vapor from the inner chamber as it passes through the small orifice into the outer chamber.

When the item under test begins to generate heat, the freon flow rate increases, which causes an increased pressure drop across the orifice. The increased output from the transducer causes the heater in the inner chamber to be turned down and a constant flow rate of freon vapor (and, therefore, a constant heat output from the inner chamber) will be maintained, provided that the inner chamber heater was originally set at some value higher than the anticipated heat output of the item under test. The heat generation rates can be read directly on a strip chart recorder.

The fabrication of a vibration, thermal vacuum cold plate, and module test fixtures will be required.

Thruster and Feed System

Functional Description

The ion thruster converts electrical energy into thrust by electrostatically accelerating charged mercury ions to a high velocity and expelling them from the spacecraft in a controlled directed beam. The propellant feed system controls and regulates the introduction of mercury propellant into the thruster to assure efficient operation.

Hardware Composition

The thruster and feed subsystem is composed of the thruster, vaporizers and isolators. Three vaporizers are required; one for the neutralizer, a second for the hollow cathode, and a third to control the main mercury flow to the discharge chamber. Two isolators, one each for the hollow cathode and discharge chamber mercury flow lines, are required to insulate the propellant tanks from the high thruster potentials.

The operating parameters for the thruster are given in Table D-2 and the physical description in Table D-3.

Similarity to Previous Designs

This type of thruster has been extensively developed and tested in designs very similar to that considered here. Because of the specific requirements of this application, minor modifications to an existing configuration are required.

Make or Buy

The thrusters and feed systems will be fabricated in-house using commercial components and materials wherever possible.

Special Processes, Materials, and Components

A number of specialized fabrication techniques, such as electron beam welding and vacuum brazing, are required for fabrication. Refractory metals of controlled porosity are needed for fabrication (including tungsten). Specially fabricated ceramics are required to provide the necessary structural and high-voltage integrity

Table D-2. Thruster Operation Parameters

Parameter	Value
Specific impulse (seconds)	3500
Input thruster power (watts)	3623
Thruster beam power (watts)	3046
Power efficiency (at rated power) (percent)	85.3
Discharge losses (at rated power) (eV/ion)	200.0
Propellant utilization efficiency (percent)	85
Acceleration-deceleration ratio	2.5
Beam current (amps)	1.8
Beam potential (volts)	1696
Thruster power losses (watts)	
Discharge	360.0
Cathode and isolator heaters	54.9
Cathode keeper	2.2
Accelerator	77.0
Neutralizer heater and vaporizer	22.8
Neutralizer keeper	2.2
Vaporizer	9.7
Cathode vaporizer	5.2
Neutralizer bias	44.9

Table D-3. Thruster Physical Description

Parameter	Value
Thruster and feed-system mass (kilograms)	3.97 (8.75 lb)
Anode diameter (centimeters)	30.0 (11.8 in.)
Outside diameter (centimeters)	40.0 (15.7 in.)
Thruster length (centimeters)	27.0 (10.6 in.)
Accelerator electrode thickness (centimeters)	0.128 (0.0504 in.)

Procurement Considerations, Problems, or Risks

While a number of specialized materials and services are required, they are all considered to be available from established industry sources.

Fabrication Considerations, Problems, or Risks

A carefully planned quality control program will be implemented to assure that the necessary formalities, documentation, inspection, etc., are maintained during the construction phase (joining and shaping ceramics, refractory metals, and cathode surfaces with stringent chemical purity requirements). All of these activities have been previously accomplished successfully.

Test Considerations, Problems, or Risks

The test program as a minimum will consist of.

Developmental tests - Preliminary vibration, thermal, and electrical tests to be performed prior to integration with the power conditioner and incorporation into the engineering model

Qualification tests - Extensive testing to qualification levels of the final thruster and feed-system configuration before and after integration with the power conditioner

Acceptance tests - Verification of the thrusters and power conditioners in an array prior to mounting on the vehicle

Equipment Required to Support Fabrication and Test

All special test facilities that are required to support both fabrication and test are available at HAC. An electron-beam welding facility, high-vacuum furnace, metallurgical and photo micrographic services, sheet metal and welding on machine shop facilities are required for fabrication. Testing requires a cryogenically lined high-vacuum facility of at least 8-foot diameter, laboratory power conditioning and control systems, plus provision for continuous and high-speed data recording. Standard vibration facilities are required for flight qualification.

Thruster Array Translator Mechanism

Functional Description

The prime function of the thruster array translator mechanism is to provide displacement in two orthogonal directions such that the resultant thrust vector produced by the ion thrusters may be aligned through the spacecraft's center of mass. Without such capability, disturbance torques resulting from center-of-mass location uncertainty, resultant thrust-vector position uncertainty, and individual engine shut-down or failure would require an exorbitant amount of compensating fuel to continuously cancel the disturbance over the long thrusting phase (approximately 200 days for the asteroid belt mission) of the mission It is mandatory that such a mechanism be provided for the reasons stated above: it is logical to utilize the device to provide stabilization and control for the spacecraft about two axes of the vehicle during the thrusting phase.

Hardware Composition

The thruster-array translator mechanism consists basically of the following elements.

A structural tray for mounting the thrusters

Guide-rail assembly which rigidly mounts to the spacecraft structure

A carriage which attaches the tray to the guide rail assembly

Four 90-degree stepper motors (two motors drive tray on carriage, and two drive carriage on guide-rail assembly)

Four gear-reduction units

Rollers and band-suspension units (Rolamite devices)

Similarity to Previous Designs

Similar designs, usually employing linear drive actuators, have been previously identified as an integral facet of an integrated propulsion system development program and therefore cannot be referred to as "off-the-shelf" hardware. Present development at JPL utilizing stepper motors, spur gears, harmonic gear drive, and output drum will definitely further the state of the art in this area.

Make or Buy

The tray, rail assembly, and carriage are make items. The stepper motors, suspension band and rollers, and gear reduction unit are very likely buy items.

Special Processes, Materials or Components

A detailed analysis of the translator mechanism was outside the scope of this study contract, and as a result, no special processes or materials can be identified. In the case of the drive motors, sealing may be a potential problem requiring special attention due to the long exposure to hard vacuum. Since the roller and band (Rolamite) devices do not have sliding friction, their lubrication is not required.

Procurement Consideration, Problems, or Risks

None are anticipated.

Fabrication Considerations, Problems, or Risks

Assuming the use of aluminum for the major structural elements, no fabrication problems are foreseen. The thermal environment may induce alignment problems from differential expansion, although expansion considerations should be considered in designing the mechanism, and/or control logic subsystem.

Test Considerations, Problems or Risks

The testing of the translator mechanism will include:

Breadboard tests to identify any existing problems associated with the power supply and controls interface

Development tests to identify any vibration, shock, thermal, or electrical problems

Qualification tests to extensively check out the module at qualification testing levels of vibration, shock, and thermal vacuum

Acceptance tests to the environmental levels expected to be encountered during the mission

Acceptance tests to the environmental levels expected to be encountered during the mission

Equipment Requirement to Support Fabrication and Test

No special test equipment is required to support the development, fabrication and testing of the translator mechanism.

Thruster Module Gimbal Mechanism

Functional Description

The principal function of the gimbal mechanism is to provide attitude control of the spacecraft about the spacecraft axis parallel to the resultant thrust vector. In addition, the gimbal mechanism on the thruster modules allows cancellation of any "swirl" torques produced by the engines themselves during the powered phase of the trajectory.

Hardware Composition

The gimbal mechanism hardware consists of the following elements:

A trunnion-mount adapter plate that attaches to the base mounting studs of the thruster

Two bearing angle brackets with thermal and electrical isolator pads

A stepper motor and associated gear-reduction drive assembly

Similarity to Previous Design

Gimbal mechanisms are considered state-of-the-art, although for the application considered, the gimbals must be included as an integral part of the integrated electric propulsion system development.

Make or Buy

Stepper motors and gear-reduction drive are buy items. The trunnion-mount adapter and brackets are make items.

Special Processes, Materials or Components

Sealing of the stepper motor and gear-reduction unit may require special processes. The proximity of the thruster may require thermal protection of these devices. Further analyses will be required in this area.

Procurement Consideration, Problems or Risks

None are anticipated.

Fabrication Considerations, Problems or Risks

None are anticipated.

Test Considerations, Problems or Risks

The gimbal mechanism will undergo development, qualification, and acceptance test levels. Specific consideration will be given to the latching device supporting the thruster modules during the severe-launch environment of vibration and shock. A pin-puller device may be incorporated in the bracket design supporting the trunnion opposite the drive mechanism.

Equipment Requirement to Support Fabrication and Test

No special equipment is anticipated.

Reservoir and Feed Lines

Functional Description

The reservoir (tanks) store liquid mercury under a controlled pressure of approximately two atmospheres during the mission. The feed lines and associated valves control the distribution of liquid mercury to the three vaporizers where it is converted to a vapor and injected into the thruster.

Hardware Composition

The 109.2 Kg of mercury required for the mission is contained in a single spherical reservoir. The tank is constructed from stainless steel and the internal bladder from neoprene. The pressurizing fluid is freon. The critical dimensions of the tank are given in Table D-4.

Similarity to Previous Designs

Figure D-5 illustrates the configuration for the propellant tank. This design is representative of the reservoir concepts employed for the NASA LRC SERT II test flight scheduled for early 1970 and for the JPL propulsion system development programs.

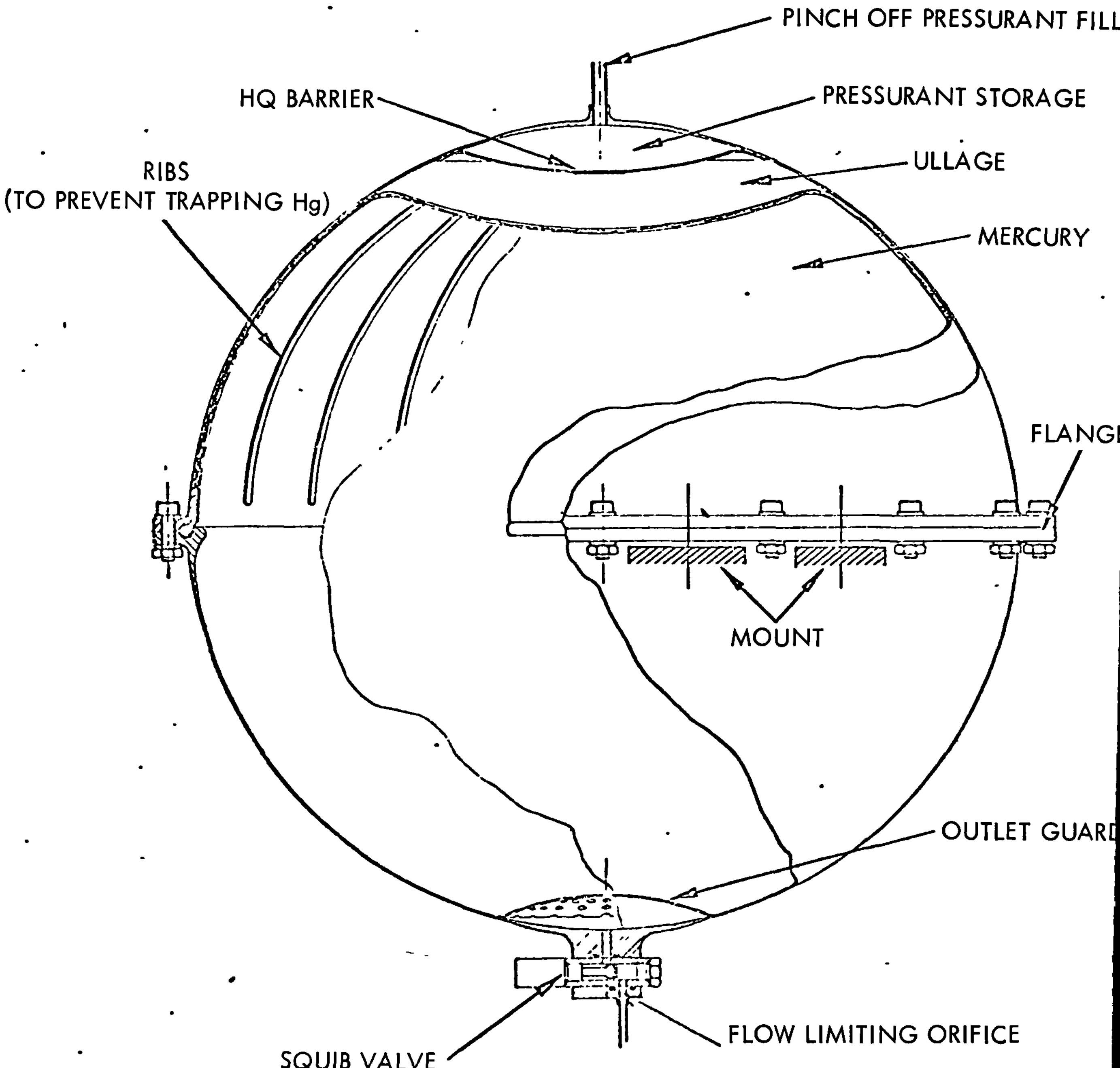


Figure D-5. Propellant Tank Configuration

Table D-4. Tank Dimensions

Parameter	Value
Propellant mass (kilograms)	109.2
Tank mass (kilograms)	2.27
Tank volume (meter^3)	0.00944 (9440 cc, 576 in.^{3})
Mercury volume (meter^3)	0.00806 (8060 cc, 492 in.^{3})
Ullage (percent)	5
Miscellaneous (percent)	1
Dispersion Allowance (percent)	10
Tank diameter (meter)	0.262
Tank reliability	0.9992

Make or Buy

Both the tank and bladder will be subcontracted and controlled by component specification.

Special Processes, Materials, and Components

Special facilities are required to handle the mercury safely and without contamination.

Procurement Considerations

No problems are anticipated in the procurement of the specially designed and fabricated feed system components.

Fabrication Considerations

No special problems are anticipated during fabrication and assembly of the reservoirs or the feed lines.

Test Considerations

The propellant reservoirs will be incorporated into each of the test systems listed under thruster.

Equipment Required to Support Fabrication and Test

The above-mentioned mercury handling facilities plus a clean room for assembly will be required. Standard vibration and environmental facilities are needed for testing.

Part 2 - Manufacturing Plan

Purpose

This plan describes the subcontractor's manufacturing role for the electric propulsion system for the solar electric propulsion asteroid belt spacecraft. The manufacturing plan is primarily implemented during the Phase D of the program, although manufacturing and engineering personnel are closely involved during the earlier phases in developing the detailed manufacturing plans for the project.

Scope

For this project, the electric propulsion system integration and assembly will be accomplished by the Satellite Systems Manufacturing Department of the El Segundo Manufacturing Division of the Hughes Aircraft Company. This plan is based on the results of this contract's electric propulsion system study efforts and the Phase D master-phasing schedule developed for the project. The final electric propulsion system manufacturing plan should cover all the system integration, testing, assembly, and qualification of the complete propulsion system; i. e., thruster array, thruster feed system, translator and support tray, gimbal, power conditioner, reservoir, and controls for the asteroid belt spacecraft. The integration of the propulsion system into the spacecraft structure is illustrated in Figure D-6.

Manufacturing Schedule

The planned schedule for manufacturing the hardware requirements of the electric propulsion system is presented in Figure D-7. This schedule is based upon a total requirement for one engineering model, one qualification model, and two flight models. Procurement actions will be initiated at contract go-ahead and will be implemented starting with the receipt of the advance bill of materials after the first month. Initial procurement deliveries will permit fabrication to commence concurrently with the manufacturing drawing release scheduled for the end of the third month.

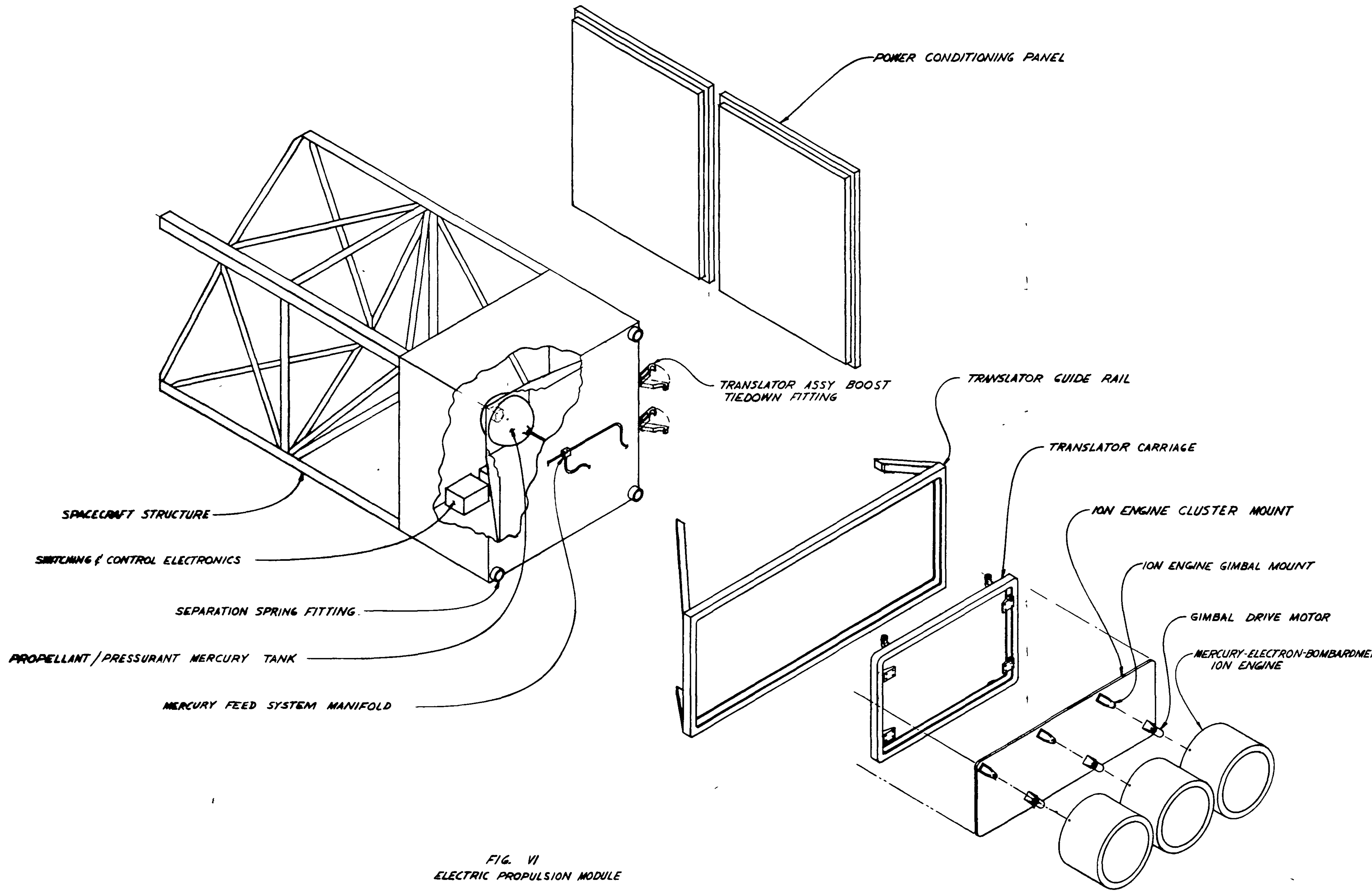


Figure D-6. Electric Propulsion System Assembly Sequence

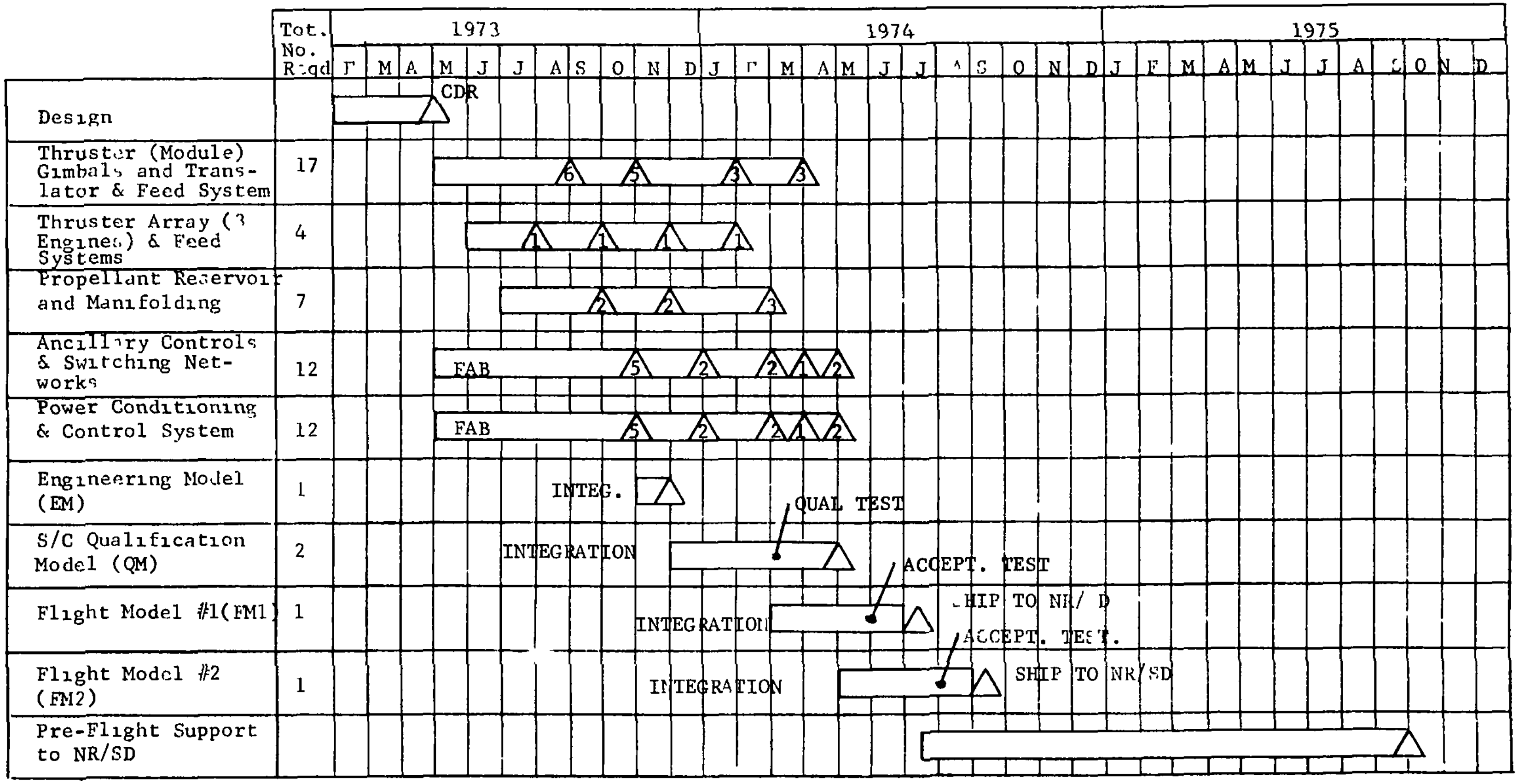


Figure D-7. Electric Propulsion System Hardware Schedule

Material. Upon release of an advance bill of material (ABM) for each unit and system by engineering, the Manufacturing division immediately initiates procurement activity for the components listed. Because of the long lead time required for most high-reliability components, and also because of their high cost, every effort is made to combine all identical parts on one purchase order This results frequently in quantity price breaks and single "lot acceptance."

Upon release of the engineering drawings, the requirements thereon are compared with those established by ABM and all procurements adjusted accordingly. Since the ABM at this point is superseded by the drawings, all further changes to component requirements will be accomplished by drawing revisions.

When received, all high-reliability components are inspected and tested. After being individually packaged, identified, and serialized, these components are placed in a bonded stores room segregated by part number and project, and retained until a kit requisition is initiated by planning personnel to withdraw them for assembly. The kit requisition form will be completed by stores personnel, listing the part serial number and purchase order number against which it was procured. This kit requisition, when signed by the stores personnel, will become a permanent part of the equipment log for each unit.

Quality Assurance. The quality assurance activity within Manufacturing begins immediately upon Phase D contract go-ahead with implementation of the Manufacturing Plan. Upon receipt, all components are inspected and tested as required by Quality Control personnel from Engineering-prepared specifications. All production planning prepared for the assembly of the test and flight models will have as its first operation "QC screen planning." Upon buy-off of this operation prior to release, Quality Assurance will confirm that sufficient inspection points have been included at appropriate steps in the planning to ensure compliance with all drawings and contract requirements. As each model progresses through its various stages of assembly and test, the equipment log book, initiated by Planning, will undergo constant surveillance to assure that it contains all historical data required.

Configuration Control Interface. For all drawings released for this program, a planning-history folder will be established. Included in this history folder will be a copy of each drawing and the master planning sheets. The master planning sheets will reflect the drawing number, drawing change letter, and all engineering change order numbers to which the planning was written. Every time a change document is released, this folder, together with the change document, will automatically be routed to the responsible

planner for evaluation and action. Each equipment log book will contain a copy of the planning to which the assembly was manufactured. It will graphically display any and all changes made to the planning, the date the change was made, and the planner making the change.

Manufacturing - El Segundo Manufacturing Division. Buildings 350 and 358 are an integrated facility capable of complete production of advanced electronic weapons systems and spacecraft. Clean rooms, bonded storerooms, standards laboratories, and an analog computer complex, as well as scientific, engineering, and administrative offices and many specialized laboratories are available.

The assembly of the engineering, qualification, and flight models of the power conditioners will be done at this location. It is anticipated that only the shop aid type of equipment will be used in this area.

Figures D-8 through D-13 show a few of the clean room areas in the Manufacturing facility, Building 358.

Part 3 - Development and Production Test Plan

Purpose

Tests to be performed will demonstrate that all major elements of the propulsion module, namely the power conditioning and control system, thruster and feed system, and gimballing and translating devices will meet the specified requirements at qualification or flight-acceptance levels.

Scope

This test plan covers the type of tests that the major elements of the electric propulsion system will be subjected to during Phase D.

Specifications and Procedures

During Phase C, test specifications and procedures will be prepared for all major tests. These test specifications will describe the items to be tested, the purpose of the tests, the level of testing, test conditions, procedures, equipment, and facilities required, parameters to be evaluated, data to be recorded, and tolerances. Copies of all test specifications and procedures will be submitted to the spacecraft systems-integration contractor prior to testing for approval.

Figure D-8. Main Aisle, Assembly Area C

Figure D-9. Work Station, Array Assembly Area C

Figure D-10. Electronic, Battery and Wiring Assembly Area C

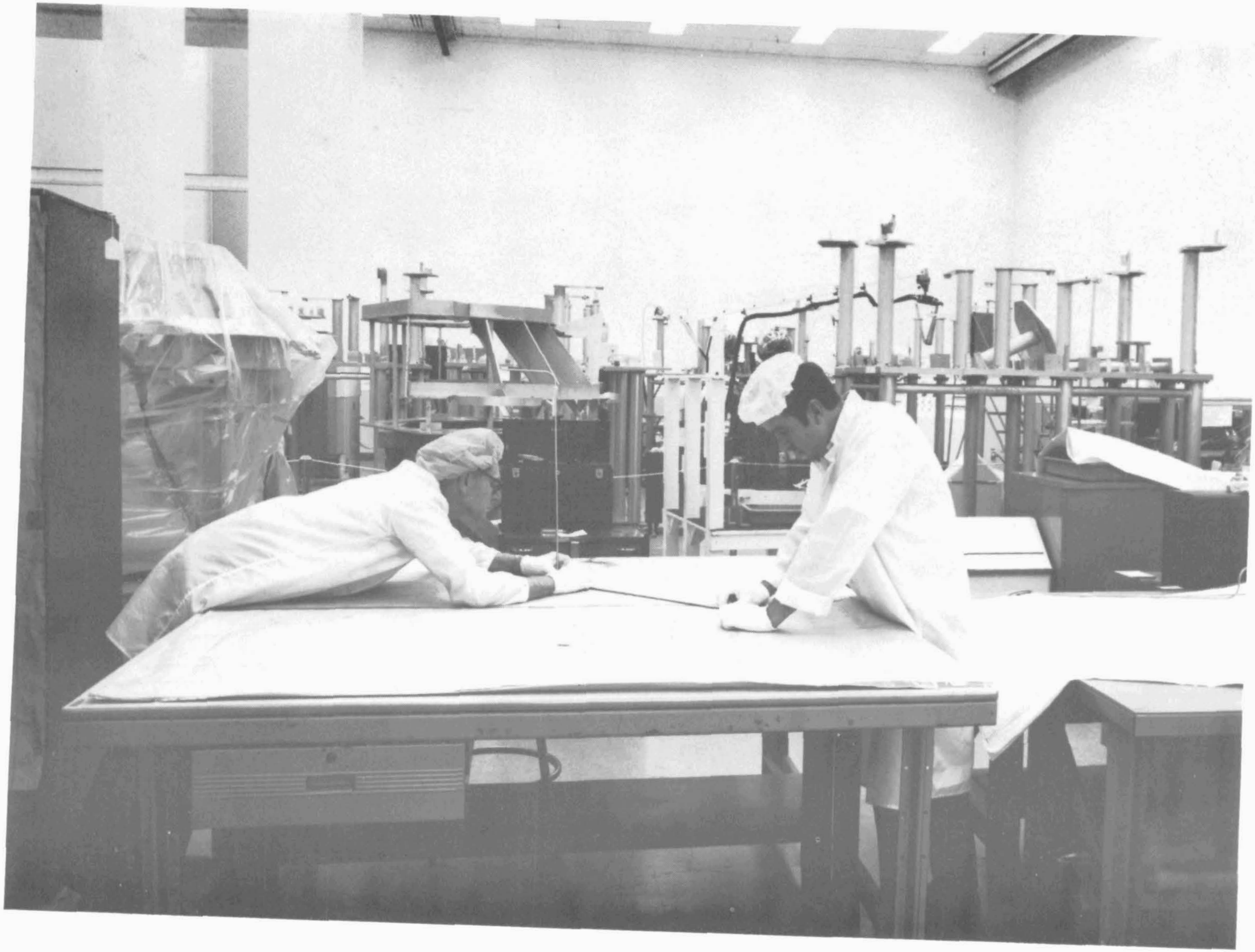


Figure D-11. Pneumatic Layout Area C

Figure D-12. Laminar Layout Area C

Figure D-13. Sunshield Assembly Area C

Power Conditioning Equipment Tests

Electrical Performance Tests. All models and units will be tested to demonstrate that specified electrical requirements are satisfied. The systems test console to be used will contain all the controls, loads, and monitoring required for electrical performance testing. All models and units will be subjected to an electrical performance test following fabrication buy-off. The engineering model will be tested again following electrical stress tests and will also be tested and operated prior to, during, and after a thermal survey test. Electrical performance tests will be integrated with EMI, vibration, and shock proof-of-design testing scheduled for the engineering model. Prototype and flight units will be operated during thermal vacuum testing, and electrical performance tested after thermal vacuum, vibration, and shock flight acceptance testing.

Electrical Stress Tests. The engineering model will be subjected to an electrical stress test. Operating transients, such as startup, step change in operating magnitude, shutdown, and arcing will be simulated. Steady-state and transient electrical stress will be measured across those parts subject to transients. Transient effects due to coupling to low-voltage circuits and the effectiveness of decoupling circuits will be recorded. The test console will simulate all the required operating transients and will provide connections to the recording equipment, such as a peak reading voltmeter, oscilloscope, etc.

Thermal Survey. A preliminary thermal survey will be conducted on the engineering model. The survey will be conducted in a laboratory environment, 25 ±3 ambient with minimum convective cooling, to identify the thermal stresses. The test console will provide power conditioner control and operation and connections to temperature-monitoring equipment.

EMI Tests. EMI tests will be conducted with the power conditioner in a simulation of the vehicle enclosure, and simulating the solar array source and harness interconnections. The engineering model will be proof-of-design tested for electromagnetic interference (EMI). The test will detect EMI problems early in the program. This permits corrective action (if required) to be incorporated in the prototype and flight units.

The prototype unit will be tested for EMI. This test will demonstrate that the specified requirements are satisfied.

The level and conditions of the EMI tests will be in accordance with the following standards, under Sub-Class IIA (non-communication equipment) and the environment classified as MA u (unmanned missiles, satellites, etc.):

MIL-STD-461; (draft, dated 2 May 1966) electromagnetic interference characteristics, requirements for

MIL-STD-462; (draft, dated 2 May 1966) electromagnetic interference characteristics, measurement of

MIL-STD-463; dated 9 June 1966, electromagnetic interference characteristics, definitions and system of units

The test console will provide control and operation of the power conditioner during the test.

Thermal Vacuum Tests.

Proof-of-Design Test. The engineering model will be vacuum tested at Hughes facilities. The test will simulate the thermal-vacuum environments acting upon the propulsion module components during launch, ascent, and orbit. The level of the test will be to prove the design of the power conditioner and will include a 14-day, 24-hour-per-day, thermal vacuum soak.

The test console will provide control and operation of the power conditioner during the tests.

Flight Acceptance Tests. The prototype unit and flight units will be thermal vacuum tested to a flight acceptance level. The test conditions will not be so severe as the qualification tests, but will be in accordance with the requirements specified by the Spacecraft Integration Contractor.

All units will be tested for electrical performance after a flight acceptance test to demonstrate that no degradation has occurred.

Vibration and Shock Tests.

Proof-of-Design Tests. The engineering model will be vibrated and shocked to more stringent conditions than would be expected from transportation, handling, test, prelaunch, launch, and flight. The purpose of the test is to demonstrate the capability of the power conditioner to meet all performance requirements without harmful degradation, due to vibration and shock. The test will be performed at Hughes facilities.

The test console will operate and control the power conditioner during this test and will be used to electrical performance test the power conditioner after the test.

Hughes will perform this test on the engineering model to detect difficulty early in the program. This will permit corrective action to be taken and incorporated into the prototype and flight units without affecting the delivery schedule.

Flight Acceptance Test. The prototype unit and flight units will be subjected to the levels of vibration, shock, and acceleration expected during prelaunch, launch, and flight.

An electrical performance test will be done after the vibration and shock test to demonstrate that no degradation has occurred.

Efficiency. During the course of the program, the efficiency of the power conditioner will be measured, and it will be demonstrated that it meets the minimum requirements. Because of the frequency and the pulse-width modulation of the ac outputs, accurate power measurements are difficult. The best commercial equipment available is a 1-percent, RF thermocouple-type ammeter and a 0.5-percent RF thermocouple voltmeter. This leads to 1.5 percent power measurements. In an efficiency calculation, the accuracy drops to ±3 percent. In calculations of heat loss and required radiation area, the 3-percent tolerance can be significant.

To measure the power conditioner losses more accurately, Hughes recommends the use of a calorimeter. The calorimeter method of measuring losses permits the actual losses to be measured within 1-percent accuracy.

Extraneous Transients and Noise. Monitoring checks will be conducted during the design and development phases of the power conditioner to detect spurious and unwanted transients. This will be accomplished by monitoring various points in the circuitry with a memory, peak pulse reading voltmeter.

When the presence of a transient is detected, its origin can be traced by use of the voltmeter and an oscilloscope. Once the trouble has been determined, action can be taken to correct the situation.

Engine Test Plan. It is generally agreed that the design and subsequent performance of power conditioning equipment for ion thrusters is critically dependent on the thruster operating characteristics.

One consequence of this dependence on thruster operating characteristics is that integration tests with a thruster are a necessary part of the power conditioner design cycle. Past programs have repeatedly demonstrated that the power conditioner design cannot be finalized until the power conditioner and thruster have been integrated and performance tested together.

Thruster integration testing is required to determine the gain-frequency shaping networks required for stability of the vaporizer supply, cathode supply, neutralizer cathode, and neutralizer vaporizer supply. Other system design factors which depend on the thruster characteristics are heater-circuit time constants and resistance-versus-temperature characteristics, overload trip settings, transient suppression, ac grounding, and high-voltage output filtering.

The first test period will be for the purpose of defining the characteristics of the thruster, particularly those which influence the power conditioner design. These tests will be run with laboratory power supplies. The data from these tests will also serve as a reference base for comparison when the thruster and power conditioner are tested together. Specific objectives of this first test series will include identification of engine parameters at the specified operating point for the mission, measurement of transient voltage levels, and maximum power for setting of trip-level adjustment ranges, verification of the startup and restart sequences, determination of the approximate set-points, and performance mapping. During these tests, the thruster system will be in the same vacuum thermal environment as when operated later with the power conditioners. Performing all tests in the same environment will reduce the number of variables when comparing operation with the power conditioner to operation with laboratory supplies. To be of maximum benefit to the program, these tests should be conducted as early as possible.

The first, and probably most significant, testing of a power conditioner system with a thruster will be performed with the engineering model. The basic purpose will be to identify and correct any incompatibilities between the power conditioner and thruster system as quickly as possible so that all subsequent power conditioners can reflect any changes required. Specific items to be investigated include selection of values for gain-frequency shaping networks, operation of control loops for all set-points, reliability of startup and restart sequences, response of system to thruster-induced transients, and simulated module failures. The stability of the control system will be tested by running one continuous test of approximately 100 hours duration. By testing the first power conditioner with a thruster, two major benefits should be derived: knowledge of any changes required will be immediately available to the power conditioner designers, and the first system delivered will have demonstrated the capability of operating with a thruster.

The final test sequence that is suggested is thruster testing of the prototype model. The prototype model will be identical to the flight models in all respects that will affect flight performance. The prototype model is

also the first one required to pass vibration and shock tests. Therefore, it is proposed that the Contractor determine the performance characteristics of the prototype before and after it is subjected to the flight acceptance vibration and shock tests. The purpose of this test series would be to assess the effect, if any, of vibration and shock on electrical performance and vacuum thermal integrity and stability.

Part 4 - Ground Support Equipment (GSE) Plan

Purpose

This section of the electric propulsion system development plans briefly describes the ground support equipment (GSE) associated with the thrusters, mechanical subassembly, and the power conditioning equipment. Detailed GSE requirements will be established during Phase C. This equipment, built during Phase D, would be used to check out the electric propulsion system prior to launch.

Scope

A system test console is required to test and check out the power conditioner during prelaunch operation. The power conditioner must be checked out with simulated engine loads, since the electric propulsion system cannot be operated as a propulsion system in a prelaunch environment. The thruster will be checked out separately from the power conditioner.

GSE Description

Power Conditioner Equipment GSE. A systems-test console is required to operate and test the power conditioning equipment during the development, qualification and prelaunch operation. The primary functions of the test console are to provide the following:

Simulated loads for the power conditioner

Simulated solar panel power

Instrumentation for monitoring voltage, current, waveform, and temperature

Continual telemetry monitoring

Command generator providing analog and digital control to the power conditioner

The test console consists of two standard test equipment racks. These two racks are mounted on casters for mobility. A work shelf will be mounted across the front of the racks to provide a convenient place for writing and data recording during power-conditioner testing. Rack cooling will be provided by an exhaust fan mounted in the top of each rack and by a filtered air intake at the bottom of each rack.

The test console will be designed to operate from a four-wire, three-phase 115 volts per phase, 60-cycle power source. A three-pole circuit breaker on the front of the test console will provide master control and protection for the power to the test console. Individual units of equipment within the console will have switches and protective fusing. Current loading will be divided between the three phases as equally as possible. A separate circuit breaker controlling utility outlets will be provided for any auxiliary equipment that may be required.

The primary elements of specially built equipment for inclusion in this test console are the command generator, the load simulator, the load monitor, the input load monitor, the telemetry monitor, and the solar panel simulator. Items of commercial equipment are as follows: oscilloscope, digital voltmeter, power supply, X-Y recorder, thermistor thermometer, scanner, memory-peak voltmeter, true RMS voltmeter, and true RMS ammeter. Specific consoles will be incorporated to check out all system parameters including translating devices and gimbals.

Part 5 - Facilities Plan

Purpose

To identify the facilities that would be required and made available to support the electric propulsion system project.

Scope

The primary management responsibility for the conduct of the electric propulsion system development project will be exercised by the Hughes Space Systems Division with assistance in the following areas by the indicated activities:

Thruster and propellant-reservoir subsystem - Hughes Research Laboratories, Malibu (Division 30).

Power-conditioning subsystem development - Power Systems Department of the Space Systems Division, Engineering Laboratories.

Component selection and materials technology - Components and Materials Laboratory, Research and Development Division.

Environmental testing - Space Simulation Laboratory, Space Systems Division (Division 22).

Manufacturing - El Segundo Manufacturing Division.

Based on the conceptual system design resulting from this study, no requirement for additional facilities is foreseen for the conduct of this project. During Phases B and C, the suitability and availability of existing facilities for this project must be further evaluated.

The following summaries present a short description of the overall Company facilities and brief discussions of the specific areas which will be involved in this program.

Facilities Description

Those facilities which have proven adequate for 10 space launches (Surveyors, ATS's, Intelsat II's) are presently programmed for three launches in the future: There is no facility problem at the Hughes Aircraft Company.

Hughes Aerospace Group, together with the total resources of Hughes Aircraft Company, have over 6,500,000 square feet of combined floor space located in Los Angeles, Fullerton, and Canoga Park, California, and in Tucson, Arizona.

Hughes Aircraft Company has physical resources valued at over $304 million and employs approximately 30 thousand people in 11 major plant locations occupying approximately 6.5 million square feet of floor space and hundreds of acres of test sites and test ranges. These locations are shown in Figure D-1.

The Hughes Aerospace Group has facilities for all types of space-oriented programs. These are located in El Segundo, Culver City, the Inglewood (Airport) site, and Torrance, California. The engineering facilities of these sites contain the most up-to-date research, developmental, and test equipment to provide for a complete range from component and engineering development and fabrication to complete system engineering.

Hughes Space Systems Division is housed in a 12-story, 243,6000-square-foot office and laboratory building adjacent to the El Segundo facility. An analog computer complex and many specialized laboratories are also provided. See Figure 14.

Figure D-14. Building 366, Space Systems Division

The El Segundo facility, located immediately south of the Los Angeles International Airport, consists of 15 buildings containing 1,360,000 square feet of floor area located on a 68-acre site. The main portion of this site is an integrated facility of 750,000 square feet for the production of advanced electronic systems and complete spacecraft. The 30,000-square-foot Space Environmental Simulation Laboratory is also located at this site. This eight-story building has complete capabilities for all phases of space simulation testing of large size space vehicles.

The latest additions to the El Segundo facility are a five-story, 108,000-square-foot engineering office building and 36,000-square-foot high-bay clean-environment spacecraft assembly building. The latter will be used for Intelsat IV spacecraft assembly.

The Culver City site, consisting of 29 principal buildings located on 408 acres of land, houses the corporate executive offices, executive offices of Aerospace Group, and Headquarters of Aeronautical Systems, Research and Development, Data Systems, and Flight Test Divisions, and the supporting service activities.

The Airport Site Facility, which houses the Space Electronics Development Department, consists of 23 buildings containing over 400,000 square feet of floor space.

The Electron Dynamics Division Facility is located in a new, two-story, 165,000 square foot structure near the Torrance Airport. This building includes more than 30,000 square feet of controlled environment space for precision assembly, processing, and testing of traveling-wave tubes and related products.

Overall Company Facilities. Hughes Aircraft Company has the extensive physical facilities and equipment needed to handle a wide variety of major space and defense programs. Major sites and floor space are as follows:

Facility	Area (square feet)
Culver City	1,300,000
El Segundo	1,123,000
Fullerton	1,073,000
Malibu	101,000
Santa Barbara	56,000

Facility	Area (square feet)
Newport Beach	257,000
Oceanside	96,000
Inglewood	778,000
Tucson	960,000
Canoga Park	329,000
Other Sites	282,000
TOTAL	6,355,000

Hughes Research Laboratories (Division 30). The Research Laboratories of the Hughes Aircraft Company are located in Malibu, California. Essentially all of the thruster development work at HAC over the past 10 years has been done at this facility, which is fully equipped with all the equipment and test facilities necessary for a thruster-development program such as the one outlined here.

Space Systems Division. The Space Systems Division, with its specialized space technology laboratories and major program offices, is located in Building 366 on Imperial Highway in El Segundo just south of the Los Angeles International Airport. This modern 12-story office building (Figure D-14) is completely air-conditioned and provides an optimum environment for the development of the power-conditioning equipment related to this program.

Power Systems Department Facilities. Hughes has developed and has in operation one of the most advanced facilities in the United States for the fabrication, integration and testing of complete power systems for spacecraft.

The engineering and administration facilities to be used for the power conditioning and control system will be contained in the Space Systems Division building at the El Segundo Site.

The research and development and prototype fabrication and test facilities to be used on this project are located in the Propulsion and Power Systems Laboratory adjacent to the department office area (see Figure D-15). The labs contain environmental chambers as well as bench test and life test equipment capable of handling all phases of design and test of electrical power and control electronics. (See Figure D-16.) Remote facilities for exotic and/or hazardous testing are available.

Figure D-15. Prototype Fabrication and Test Facilities Area, Power Systems Department

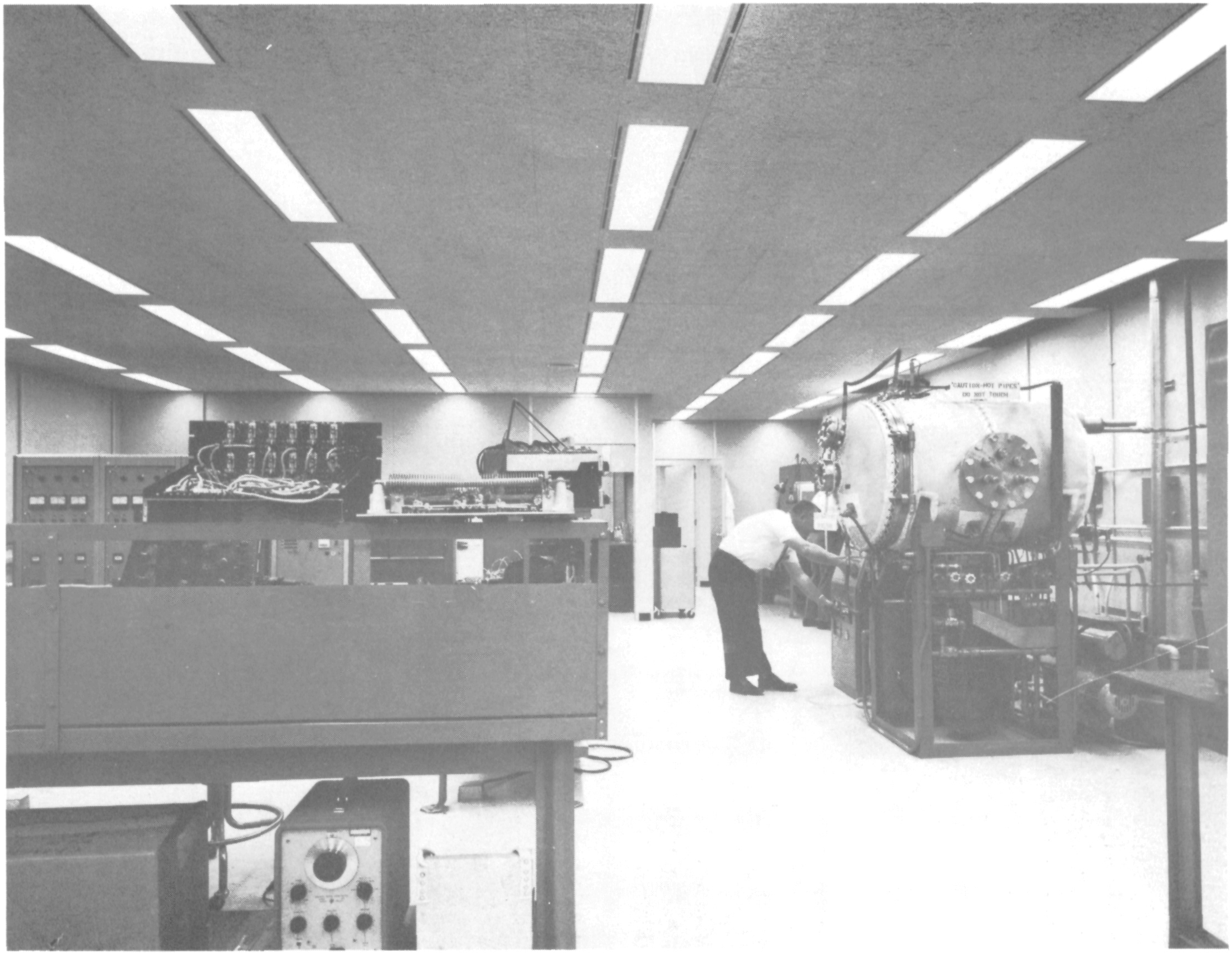


Figure D-16. Laboratory Test Facilities, Power Systems Department

Ion Thruster Test Facilities (Hughes Research Lab). Hughes Research Laboratory has been actively engaged in the research, development, and testing of ion-propulsion components and systems and in spacecraft design and mission analysis since 1959, having carried out about $15 million in contract business with NASA. During this period, the ion propulsion effort has evolved from work on basic research and component development to complete propulsion system development, testing, and flight qualification, and extensive projects in SEP missions. The projects have included the development of both cesium surface contact and mercury electron bombardment ion thrusters and complete systems using both types of propellant. The Company activity in electric propulsion, having stated in the Research Laboratories, has broadened in recent years so that it now heavily involves personnel in the Space Systems Division as well.

Technical experience has been accumulated in all facets of ion thruster testing, including design of vacuum chambers, design and fabrication of electronic test consoles, design and fabrication of ion thrusters and associated power conditioning, and finally, and most important for this project, integration of all of the above elements into a complete operating ion propulsion system of the type required by the proposed mission application. This hardware experience is vital to successful propulsion system design and optimization.

The Hughes Research Laboratories at Malibu have adequate special environmental test equipment installed to conduct a full range of ion-thruster and power-processor testing. This equipment consists of two instrumented test chambers with wide temperature and vacuum ranges, one 9 feet and the other 3 feet in diameter. The two test chambers are shown in Figures D-17 and D-18. A full complement of laboratory instrumentation and data recording equipment is also available.

Components and Materials Laboratory. The Components department of this laboratory provides components engineering services to the entire Hughes Aerospace Group. Specialists for each component part (such as resistors, capacitors, semiconductors, magnetic devices, and electromechanical devices) have accumulated years of experience in the design, testing, evaluation, and specification of components for a particular application. Their work with specific component parts, their service on national industrial and Government committees, and their continuing liaison with component manufacturers has given them a highly developed capability for selecting the right part for a given function. Representative views of this group of laboratories are given in Figures D-19 and D-20.

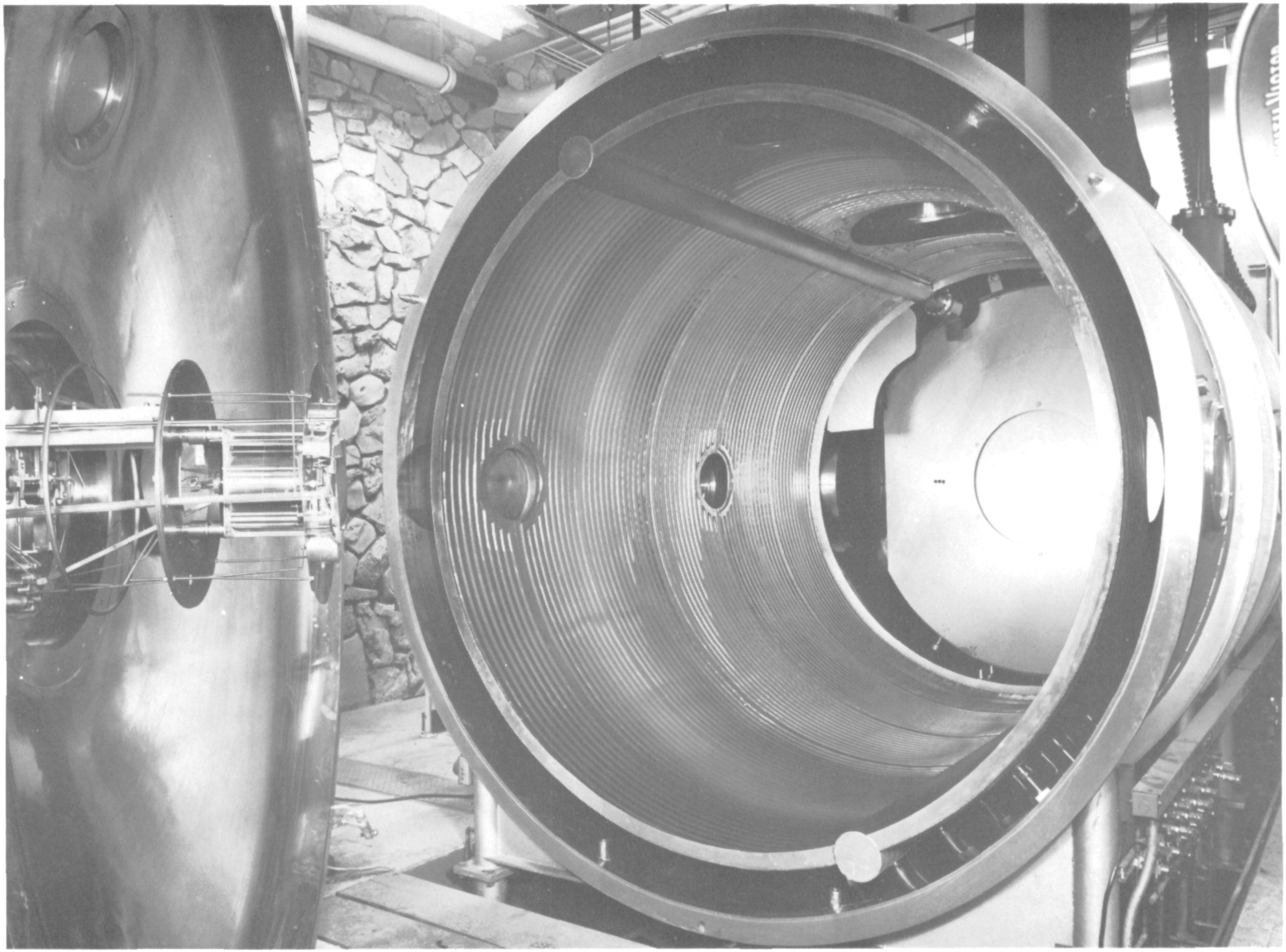


Figure D-17. Nine-Foot Chamber

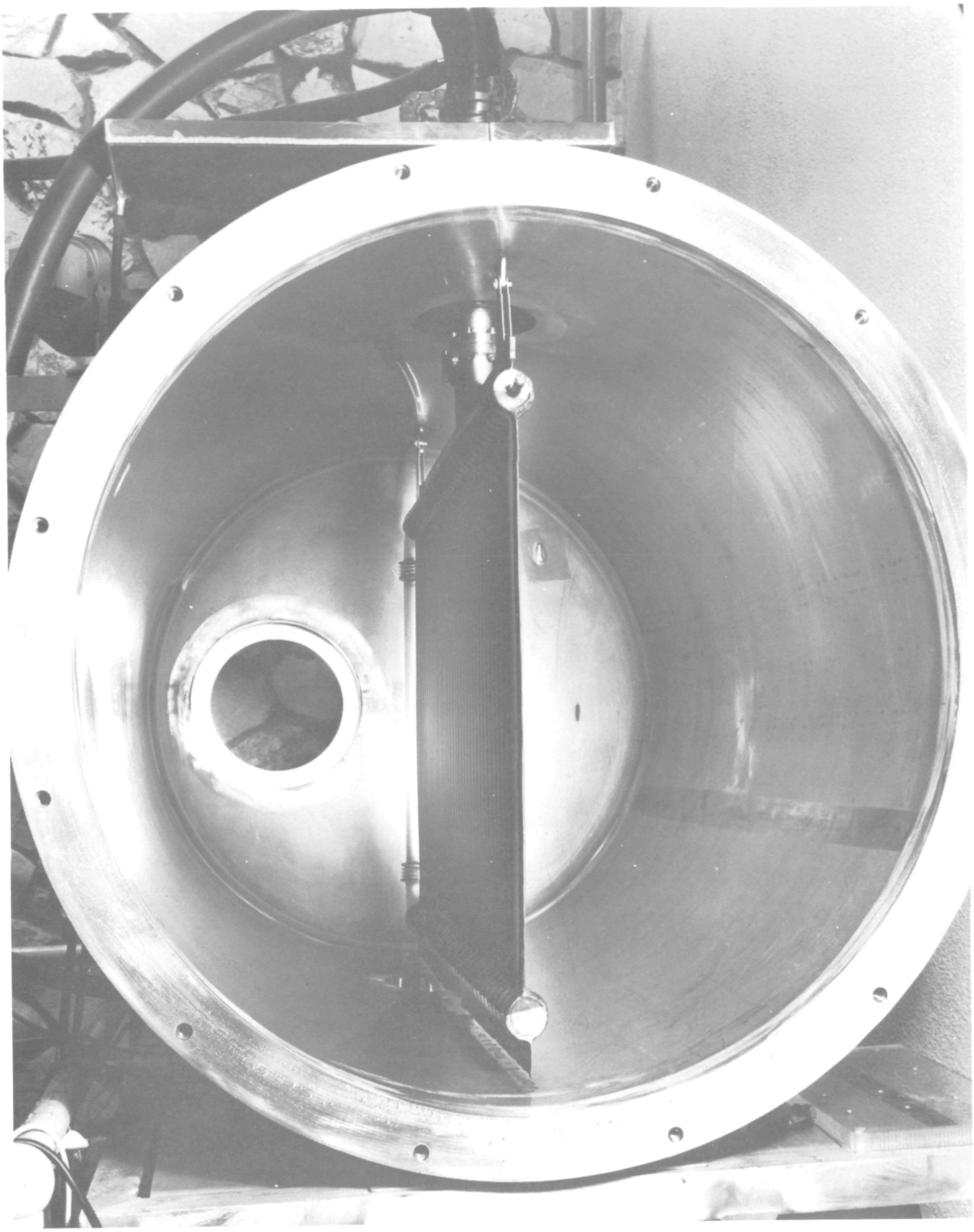


Figure D-18. Three-Foot Chamber

Figure D-19. Components Evaluation Laboratory

Figure D-20. Components Evaluation Laboratory Shielded Room

The Materials Technology department is composed of about 140 scientists, engineers, and technicians who provide materials and process engineering services to all divisions of the Aerospace Group. The high level of its consultation service to design engineers and manufacturing personnel is maintained by a continuing in-house effort divided into two areas: (1) evaluation of various materials and processes contemplated for future use, and (2) research and development aimed at establishing materials standards and processes to meet specialized requirements.

Environmental Facilities. The Environmental facilities of Hughes Space Simulation Laboratory are more than adequate for system test and checkout of the Electric Propulsion System.

The Space Environmental Simulation facilities at Hughes required for qualification and acceptance testing are located in the Space Simulation Laboratory, Building 366, at the El Segundo Site.

The Space Simulation Laboratory is an environmentally controlled facility designed and equipped to simulate the combined effects of extreme altitude, temperature, and solar radiation expected in space missions, as well as the dynamic effects of launch separation and orbital injection. Facilities include space chambers, vibration systems, test monitoring, and data acquisition systems, and solar simulation equipment. (Figures D-21 through D-23.) The Laboratory is also equipped to conduct studies in contamination effects and optics and to develop and fabricate vacuum compatible equipment.

There are eight thermal vacuum facilities, ranging in size from an 18-by-20-inch chamber for evaluating small specimens to one 15 by 36 feet capable of handling complete spacecraft and satellites.

A special feature of some of the chambers is that the top, side, and bottom thermal shrouds can be controlled individually, permitting considerable variation in temperature effects. The cold-wall, hot-surface capability, combined with solar radiation, allows accurate duplication of such conditions as lunar day or lunar night. The temperature-pressure-radiation conditions created by the chambers cover the spectrum from earth orbit to planetary flight and landing.

The sine and random vibration facility consists of two Ling L249 shaker heads, one Ling 120/150 power amplifier, and two sine-random control consoles. Either shaker can be operated separately, or both can be coupled together by means of the single amplifier-control system.

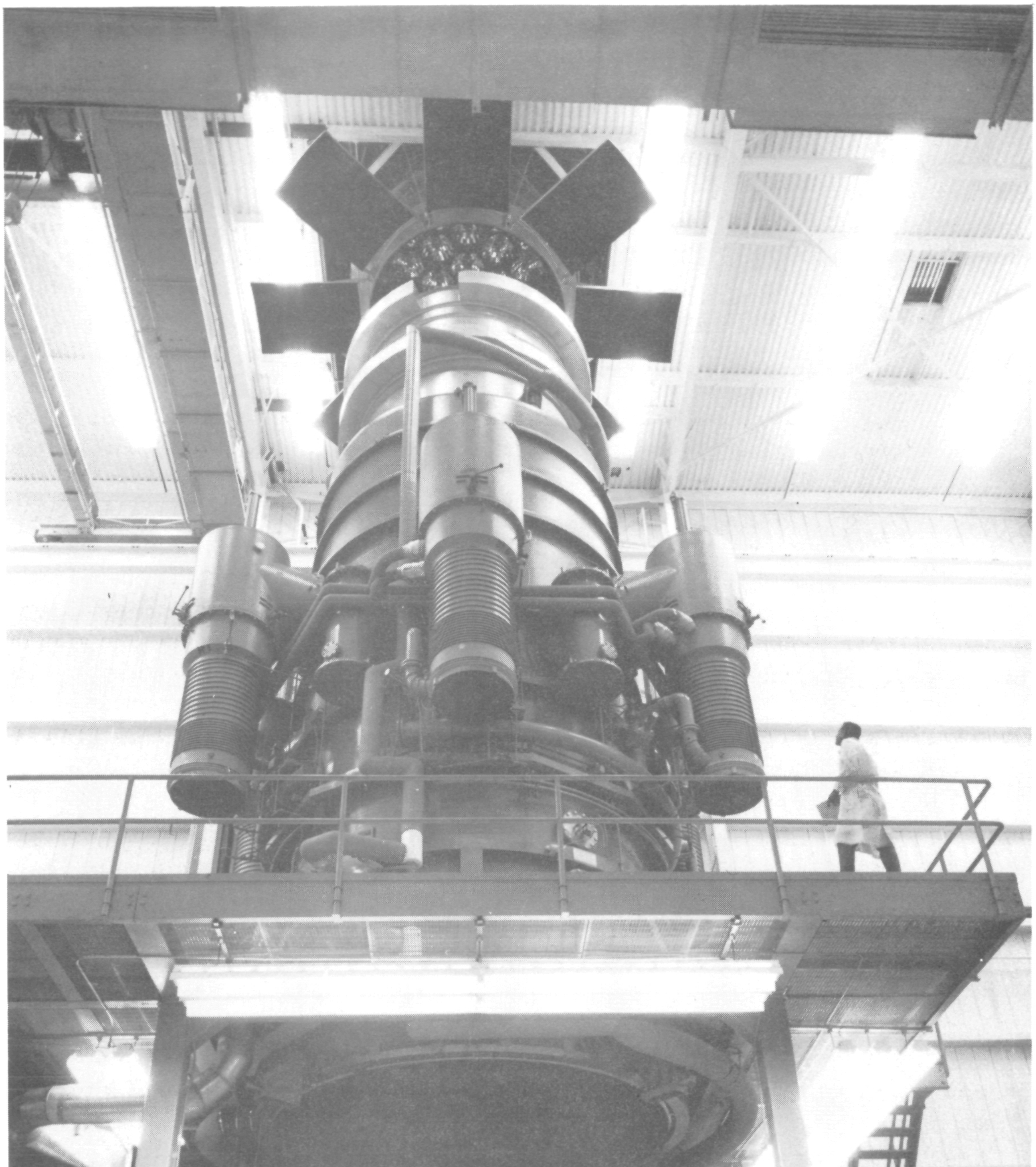


Figure D-21. Space Chamber C-4

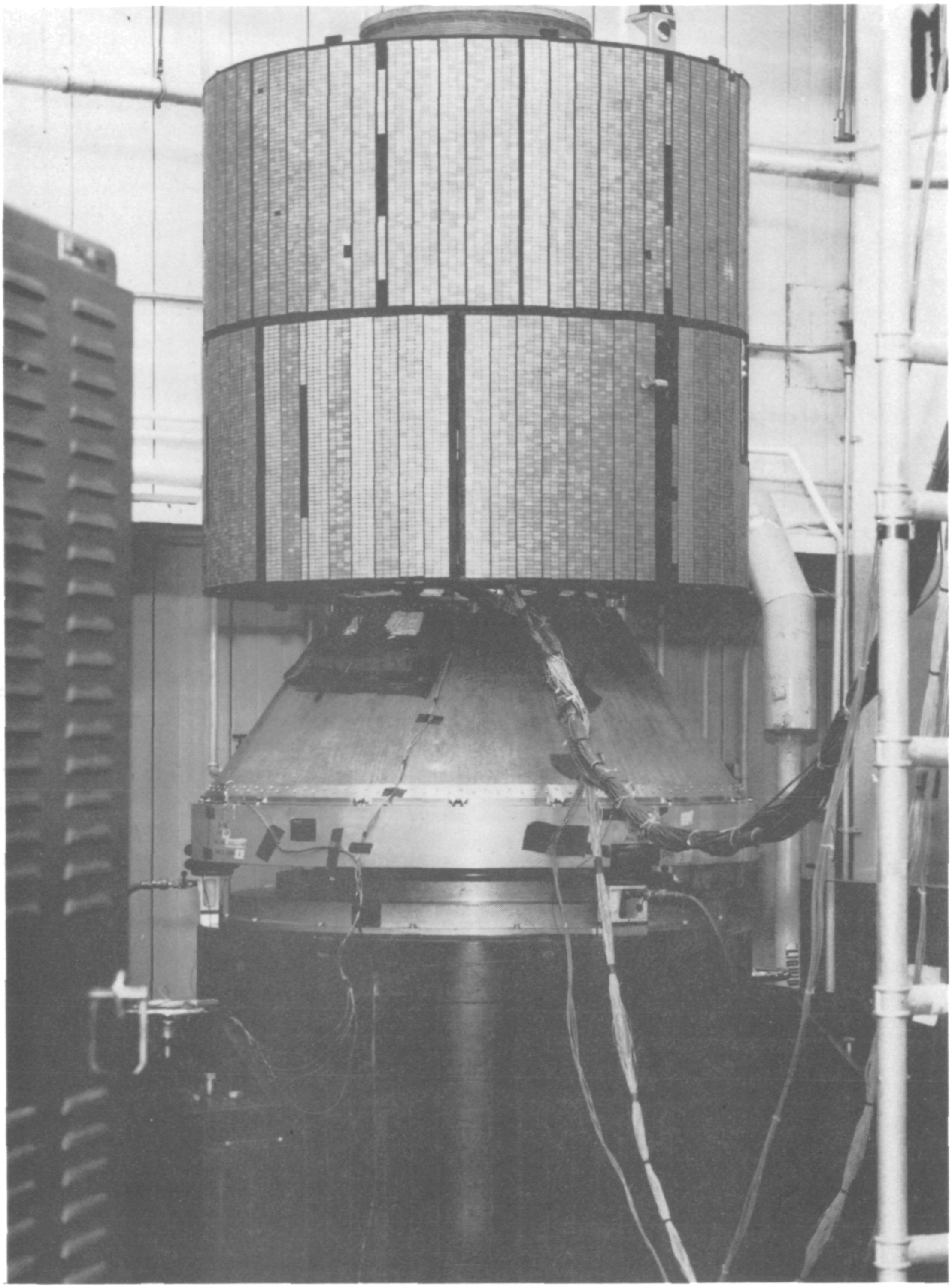


Figure D-22. Vibration Test of ATS Spacecraft

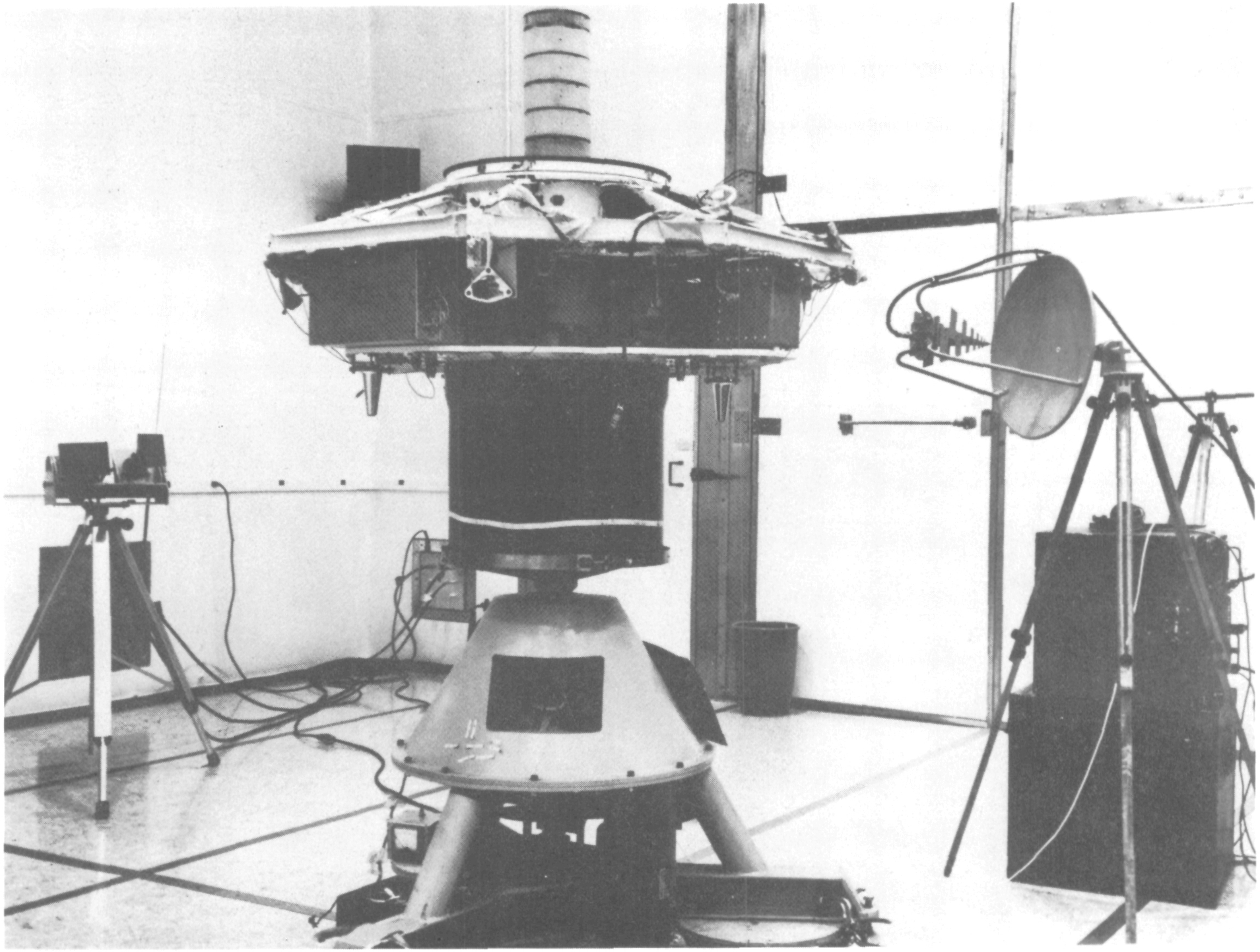


Figure D-23. EMC Testing, HS-303A

The shakers cover a frequency range of 5 to 2000 cps and are capable of providing 1-inch, double-amplitude, 70-g acceleration, 28,000 force pounds, random or sine excitation.

The control consoles include an automatic equalizer-analyzer system for the purpose of shaping the desired random spectrum. There are provisions for mixing sinusoidal and random signals for combined sine-random test requirements.

Three X-Y plotter systems are incorporated in the control consoles for "quick-look" at control accelerometer data to determine actual test levels during random and sine tests.

Data-acquisition facilities, data-reduction facilities, and the Automatic Data Monitoring System will also be available for use for this program.

Manufacturing Facilities. Adequate manufacturing, assembly, and testing facilities in El Segundo, adjacent to the Engineering offices of Space Systems Division, will be made available for the electric propulsion system.

The manufacturing facilities are located within the El Segundo Manufacturing facility. Fabrication of some subassemblies, as well as the electronics assembly will be carried out in Building 358 in the recently upgraded Class 1 environmentally controlled clean area adjacent to Building 358. Facilities for receiving and shipping and project stores are all located in Building 350 adjacent to the electronics assembly area and close to the system assembly and test area in Building 358. System assembly and test will be accomplished in Building 358 and qualification and acceptance tests in Building 365. All areas of these buildings are environmentally controlled. Various clean room areas are shown in Figures D-8 through D-13.